A HAND BOOK OF SOLAR ECLIPSES

ISABEL M. LEWIS

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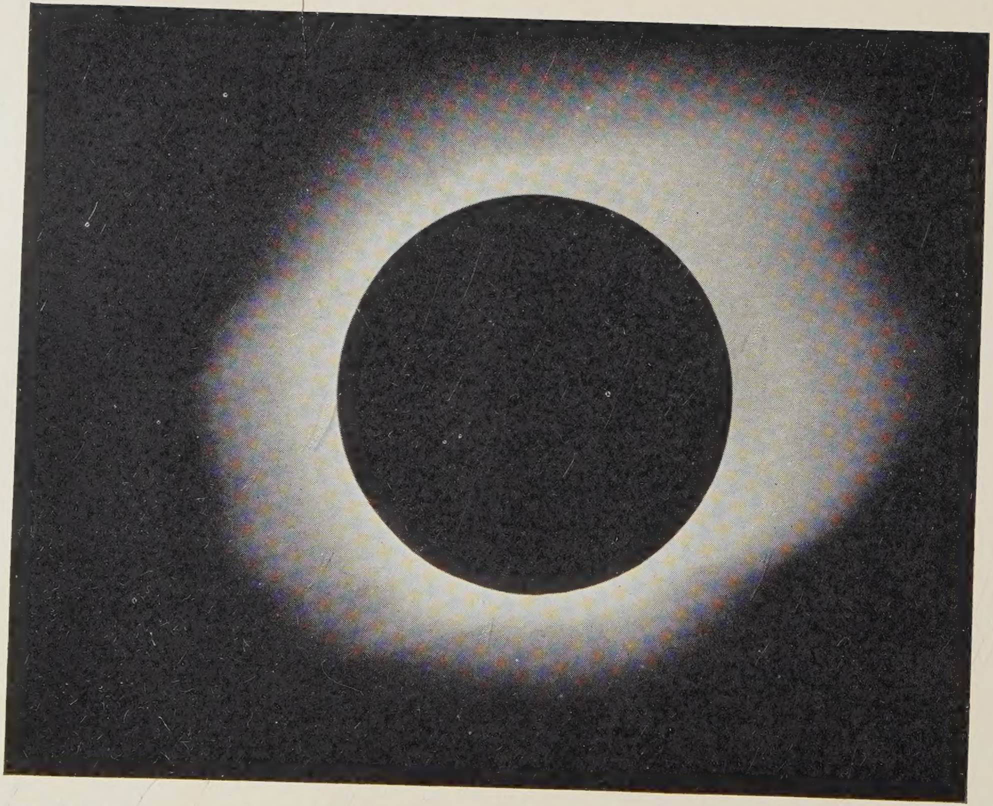

The Solar Corona photographed at Yerbanis, Mexico, September 10, 1923, by the Sproul Observatory Expedition of Swarthmore College, with camera of 65 feet focal length.

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BY

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LIST OF CHAPTERS

ILLUSTRATIONS

PREFACE

A total eclipse of the sun, an event of unusual interest and rare occurrence in any one locality, is to take place in one of the most densely populated parts of the United States, mainly in Michigan, New York State, including New York City, Connecticut and Rhode Island, on January 24, 1925. Again a total eclipse of the sun is to occur in England on June 29, 1927, the first to be visible in this country in two centuries. Many decades will pass before another total eclipse of the sun will be visible in either the northeastern part of the United States or England. As much popular interest will be aroused by the advent of these two eclipses it occurred to the writer that something on the subject of solar eclipses in general and these two eclipses in particular might not be out of place at the present time.

The aim of this little book is to present in a non-technical manner some of the chief facts concerning the cause and prediction of eclipses and their historical and scientific importance, as well as the manner in which they are observed, scientifically and otherwise.

A special chapter has been devoted to the eclipse of January 24, 1925, and a considerable part of another chapter to the eclipse of June 29, 1927, but the greater part of the book deals with phenomena observable at any total eclipse of the sun or with matter of a general nature regarding eclipses so it is hoped that the usefulness of the book will not end with the passing of these two eclipses into history.

The scientific importance of eclipses is great. Expeditions

have been sent halfway around the world to observe total eclipses of the sun.

Those who live in the north-eastern part of the United States are now to have one delivered at their doors. A number of expeditions will probably come to the path of totality of the eclipse of next January and the general public will be interested to know something of the nature of the work undertaken by such expeditions. It is also possible that the general observer of the eclipse who is located in or close to the path of totality, may make observations of real value to science during the eclipse. A few suggestions on how to observe the eclipse scientifically will be found in chapters dealing with phenomena observable at and near the time of total eclipse.

The value of two modern inventions, the moving picture camera and the aeroplane in connection with the scientific observation of total eclipses of the sun is not to be overlooked and it is to be hoped that they will both be brought to the aid of the astronomer during the coming eclipse as they were during the eclipse of September 10, 1923.

The writer wishes to take this opportunity to acknowledge her indebtedness to those who have furnished photographs or have otherwise aided in the preparation of this book.

The Superintendent of the U. S. Naval Observatory has kindly permitted the use of a photograph of the solar corona of the eclipse of June 8, 1918, obtained by the U. S. Naval Observatory Expedition to Baker, Oregon, in advance of its publication in the volume of eclipse observations now being prepared for the press at this institution. The director of the Nautical Almanac Office has also permitted the use of data bearing on the eclipse of June 29, 1927, which will be observable in England, Norway and Sweden and Siberia.

Grateful acknowledgement is also made of the kindness of Dr. John A. Miller, Director of the Sproul Observatory of Swarthmore College, in furnishing photographs of the solar corona and prominences and views of the eclipse camp and instruments taken on the occasion of the eclipse of September 10, 1923, by the Sproul Observatory Expedition to Yerbanis, Mexico.

Photographs of the solar corona of the eclipse of September 21, 1922, and views of the eclipse camp of the Lick-Crocker Eclipse Expedition which observed this eclipse at Wallal, Australia, were also kindly furnished by Dr. R. G. Aitken, Associate Director of the Lick Observatory.

A photograph of the "Heliosaurus" or "Skeleton" prominence, obtained by the Yerkes Observatory Eclipse Expedition to Matheson, Colorado, on the occasion of the total eclipse of June 8, 1918, and the series of photographs of different types of coronas shown in Plate VI were obtained through the courtesy of Dr. E. B. Frost, Director of the Yerkes Observatory and permission to use the photograph of the solar prominence shown in Plate X, taken at Mount Wilson without an eclipse, was obtained from Dr. W. S. Adams, Director of the Mt. Wilson Observatory.

Mention should also be made of the excellent work done by Mr. Alvin R. Meissner, Engraver, Washington, D. C., in preparing an eclipse design for the cover from a preliminary draft, and also the two charts, showing some eclipse tracks of the present century and the path of the total eclipse of January 24, 1925, respectively.

WASHINGTON, D. C.
July 14, 1924.

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I

THE GRANDEUR OF A TOTAL SOLAR ECLIPSE

From time immemorial man has been strangely impressed by the phenomenon of a total eclipse of the sun, which is the most sublime and awe-inspiring sight that nature affords. Among the early tribes and races of men the feeling excited by the gradual blotting out of the sun was one of abject terror. To many it was a sign of the wrath of the gods and all haste was made to appease them. To others it was a portent of misfortune in battle or the death of a ruler. In India and China, it was the belief that the darkness of eclipse was caused by a dragon with black claws who was attempting to devour the sun and it was the chief duty of the astronomers of those countries at time of eclipse to shoot arrows, beat gongs and employ similar devices to frighten away this dragon with the black claws.

In the middle ages the fear of eclipses seemed in no degree abated for we read of men hiding in cellars during totality, of women screaming and fainting and of the death by fright of the timid Emperor Louis of Bavaria following a total eclipse of the sun in the year A. D. 840 which had the more than average duration of five minutes.

Even at the present time when the cause of eclipses is so generally understood and keen scientific enthusiasm has displaced the terror of past ages a hush of expectancy and a

feeling almost of uneasiness settles over all as the slender crescent of the disappearing sun rapidly narrows to the vanishing point. Man is then, more than at any other time, brought into touch for a few fleeting moments with forces over which he can have no control and the thought awes him and brings with it an unconscious feeling of humility.

To witness a total eclipse of the sun is a privilege that comes, in general, to but few people. Many live and die without ever beholding one. Once seen, however, it is a phenomenon never to be forgotten. The black body of the moon standing out, a huge globe, in sinister relief between sun and earth, the sudden outflashing glory and radiance of the pearly corona which can be seen at no other time, the scarlet prominences rising from the surface of the hidden sun to heights of many thousand miles, the unaccustomed presence of the brighter stars and planets in the daytime, the darkness of twilight and the unusual chill in the air, there is something in it all that affects even the strongest nerves and it is almost with a sigh of relief that we hail the return of the friendly sun.

III

THE MOON'S SHADOW-CONE AND THE PATH OF TOTAL ECLIPSE

The shadow cast by a planet or its satellite into space is coneshaped, as this is the form of shadow cast by a sphere and these bodies are spheres. When this shadow-cone is intercepted by another body in space one of two things will happen depending upon the relative sizes and distances of the two bodies. If the body upon which the shadow falls is small compared to the body casting the shadow and at no great distance from it, then it will pass into the shadow of the larger body partly or completely and will be eclipsed. This is what happens when the shadow of the earth strikes the moon. As the diameter of the earth's shadow at the distance of the moon is about twice that of the moon itself the moon may be completely emersed in the earth's shadow for nearly two hours. Also the four largest satellites of Jupiter are so small compared with the huge shadow cast by this giant planet of the solar system that they are continually passing into the shadow of Jupiter for long periods. If, on the other hand, the body casting the shadow is the smaller body, as when the moon casts its shadow upon the earth, or one of the satellites of Jupiter casts its shadow upou this huge planet, then an observer looking down from space would see a small black dot passing across the illuminated surface of the planet. This black dot represents the intersection of the shadow-cone of the smaller body with the surface of the larger body.

Many who have had an opportunity to look at Jupiter

through the telescope have seen these shadows of the satellites passing across the surface of the planet. This is also what happens when our satellite the moon passes between earth and sun. The shadow-cone of the moon strikes the earth's surface and the shadow travels as a small circular dark spot across the earth's surface from west to east. The trail of this black spot across the earth is the path of total solar eclipse and anyone who is within it will see the sun totally eclipsed by the moon. It is usually about five thousand miles long and it cannot be more than about 170 miles in width. In space the shadow of the moon moves about 2100 miles an hour. But when it strikes the earth, on account of the turning of the earth on its axis in the same direction in which the shadow is moving, from west to east, the shadow has to overtake and pass a moving point and so its motion with respect to the observer is less than it is in free space. At the equator the observer is moving at the rate of 1040 miles an hour but in 45° north latitude he is moving only at the rate of 735 miles per hour. So at the equator the moon's shadow will pass the observer at the rate of 2100-1040 or 1060 miles an hour, while in 45° north or south latitude it will pass the observer at the rate of 2100-735 or 1365 miles per hour. As the duration of total eclipse at any point in the path depends upon how long it takes this shadow to pass the observer it is evident that the longest duration of total eclipse will be at the equator, where the observer is being carried eastward by the earth's rotation most rapidly. Under the most favorable combination of circumstances which occur when the sun is farthest from the earth and the moon nearest to the earth with the observer at the equator and the eclipse occurring at noon the maximum duration of a total eclipse of the sun is 7 minutes 58 seconds.

The average duration of a total solar eclipse, however, is probably about three minutes.

Now the relative positions of the sun, moon and earth are such that the vertex of the cone of the shadow may sometimes fall short of the earth's surface and in that case we have what is known as an annular eclipse of the sun. That is, the moon is not quite able to cover the disk of the sun and a small ring or annulus of light is seen surrounding the dark disk of the moon at time of greatest eclipse. The vertex of the shadow-cone, it can be shown, may fall short of the earth's surface by as much as 20,000 miles and at the other extreme it may extend about 18,000 miles beyond the earth's surface. Again the vertex of the cone may just graze the surface of the earth and the eclipse may even be annular at the ends and total in the middle of its path. In this case the duration of totality dwindles down to a second or so and the width of the shadow path to practically zero. Outside of the path of total eclipse, on either side of it to a distance of between 2000 and 3000 miles, the moon will partially cover the disk of the sun and a partial solar eclipse will be visible. The magnitude of the greatest obscuration of the sun by the moon for a point outside the path of total eclipse will depend upon the distance of the observer from the path. The nearer the observer is to the path of total eclipse the greater will be the maximum partial eclipse. If the eclipse is total its magnitude is said to be 100 per cent., if half the diameter of the sun is covered by the moon the magnitude is 50 per cent. At the outer limit of the partial phase of the eclipse there will be a mere graze of the disks of sun and moon with no eclipse visible to the eye.

IV

THE SAROS AND ECLIPSE SERIES

It is a curious fact that after a definite interval of time an eclipse, whether of sun or moon, will repeat itself, or 'return,' as we might say. Given sun, moon and earth in line at, or close to, one of the nodes of the moon's orbit, a condition which will result in an eclipse,—of sun at new moon and of moon at full moon,—then after a certain interval of time, known as the eclipse Saros, which is 18 years, 10⅓ days in length, if five leap years intervene, and 18 years, 11⅓ days if four leap years intervene, there will be another eclipse at the same node that will closely resemble the first one.

Though we do not wish to enter into the mathematics of eclipse here, it may be said that this periodic recurrence of eclipses in series follows from the fact that in this period which is equal to about 6585⅓ days there are exactly 223 lunations, or returns of new moon, 242 returns of the moon to its node, and 19 returns of the sun to the same node. So that at the end of the Saros period sun, moon and earth will be in line again at the same node under practically the same circumstances as before and another eclipse will be bound to occur under nearly the same conditions as the earlier eclipse.

Considering now only solar eclipses, the chief difference between two eclipses separated by the Saros interval will be in the location of the path of the moon's shadow on the earth's surface. Since there is a fraction of about one-third of a

day in the Saros and since in this third of a day the earth is not standing still but turning in an eastward direction on its axis the shadow of the moon will fall about one-third of a revolution of 120 degrees in longitude westward of its previous position. Compare for example the total solar eclipse of June 8, 1918 with the total solar eclipse of May 28, 1900. The 1918 eclipse was a return of the 1900 eclipse.

The duration of each eclipse was a little over two minutes and the circumstances of the two eclipses were very similar. Consider, however, the position of the middle of the path of total eclipse for each one, where the eclipse occurred at local noon. In the 1900 eclipse the position of this point was in 45° west longitude and 45° north latitude. In the 1918 eclipse it was in 151° west longitude and 51° north latitude, a difference of 107° in longitude. This is about 120° westward of the previous track as required by theory, the fraction of the day being not exactly one-third and the other factors affecting the position to some slight extent. If we wish to find the next eclipse in this series we add 18 years eleven days to the date of the 1918 eclipse and find that there will be an eclipse on June 19, 1936. We can check the accuracy of our prediction by referring to Oppolzer's Canon Der Finsternisse, in which are given the approximate elements of the 8000 solar and 5200 lunar eclipses that occur between the dates 1208 B. C. and 2162 A. D. with 160 charts that show the tracks of all the principal total and annual eclipses. Here we find listed a total solar eclipse of two and one-half minutes duration for June 19, 1936 visible from Greece to Japan.

The word Saros, used to denote the interval between successive eclipses of the same series, means "repetition" and it is believed that the Saros was first discovered and used by the Chaldeans in predicting the occurrence of eclipses. It is cer-

tain that the Chaldeans kept careful records of eclipses for centuries and were the greatest astronomers of ancient times. It is likely that Thales made use of the Saros in predicting his famous eclipse of 585 B. C. which ended the battle between the Lydians and the Medes. It was frequently made use of later, by the Greeks and others and is, in fact, used at the present time if a first rough approximation to the times of future eclipses is desired.

A second most interesting feature of this periodic return of eclipses in series arises from the fact that at each return to the node the line of conjunction of sun, moon and earth shifts westward about half a degree which in the case of solar eclipses produces a change in the position of successive eclipses of the series in latitude on the earth's surface. The first eclipse in a series will occur when sun, moon and earth are in line about 18°, or possibly somewhat less, to the east of the node. The central line or axis of the moon's shadow-cone will then pass about two thousand miles or so above the north pole of the earth or below the south pole depending upon which of its two nodes the moon is near. In this case the moon's cone of shadow will not touch the surface of the earth but there will be a small partial eclipse at and near the pole. This is due to the fact that there is outside of the true shadow-cone a sort of negative or penumbral cone as it is called, to distinguish it from the true or umbral cone, which has a diameter of about 4400 miles and within this penumbral cone the sun is seen to be more or less partially obscured by the moon. A series first enters then, at one of the poles of the earth with the falling of a small part of the penumbral shadow over the polar regions. At the next return, after the Saros interval, there will be a little larger partial eclipse at the pole but still the axis of the moon's shadow-cone will be

off the earth. After about ten or eleven returns of the Saros and a lapse of two hundred years the true shadow-cone will strike the earth near the pole and there will be a path of total or annular eclipse curving around or through the pole and a little more than half of the penumbral shadow will also be on the earth. Now for about seven and a half centuries there will be at each return of the eclipse a path of total or annular eclipse which is working gradually toward the other pole. The series will be at its height when the track passes through equatorial regions and when the penumbral shadow, which is between four and five thousand miles wide, is entirely on the earth.

After an interval of about 750 years the axis of the moon's shadow-cone will pass off the earth at the opposite pole and then there will be for another two hundred years partial solar eclipses near this pole of the earth, gradually decreasing in size at each return of the eclipse until finally, after there have been about ten partial eclipses, the penumbral shadow will also leave the earth and the series will die out at the pole opposite to the one at which it first appeared. The entire series from the time of its first appearance at one pole to its disappearance at the other lasts about 1150 years. In this time there will be visible about 64 eclipses of which 43 or 44 will probably be total or annular, and the remainder partial in polar regions.

As there are every year at least two solar eclipses while there may, in rare cases, be as many as five, it is evident that there are a number of eclipses series continually passing over the earth's surface year by year. There are new series starting in at both poles and old series dying out and there are series at their height with long tracks of total eclipse passing over the equatorial regions where the duration is longest and

the path widest. Some of these various eclipse tracks are bound to intersect and one who lives at their point of intersection may see, if they are not many years apart in occurrence two total eclipses of the sun at short intervals, without going away from home. This occurred for example in the Yellowstone National Park where, within less than eleven years, there were two total solar eclipses, one July 29, 1878 and the other on January 1, 1889. At times certain portions of the earth's surface will seem to be particularly favored by eclipse tracks. In the middle ages Scotland seemed to get more than its share of attention, five total eclipses occurring in Edinburgh within a few centuries. Spain has been particularly favored in the past hundred years. Sumatra had a fine total eclipse in 1901 most successfully observed by an expedition from the U. S. Naval Observatory and it will have two more total solar eclipses in the immediate future, one on January 14, 1926, and the other on May 9, 1929. On the other hand London went over eight hundred years from A. D. 878 to A. D. 1715 without a total solar eclipse and it has had none since and is not likely to have one for another century at least though on June 29, 1927 there will be a total eclipse of short duration visible as near to London as Liverpool and a partial phase of 95 per cent. in London.

New York City, which so far in its history has never been visited by a total solar eclipse, will find itself on the southern limit of the path of total eclipse on January 24, 1925, with a duration of total eclipse of half a minute.

V

PAST AND PRESENT PREDICTIONS OF ECLIPSES

In early ages the accurate prediction of the circumstances of an eclipse of the sun was impossible. The Chaldeans had, to be sure, discovered the Saros by means of which the times of the occurrence of future eclipses could be predicted with a fair degree of accuracy. But to predict the course that would be taken by the moon's shadow over the surface of the earth was quite another matter. This depends not only on the positions of the sun and moon in the heavens but also on the size and shape of the earth and the motion of the observer with respect to the shadow, due to the rotation of the earth, matters of which the early astronomers knew next to nothing.

If it happened that an eclipse of the sun were total in the afternoon at a certain point in Asia Minor or Greece, then at its next return eighteen years later the path of the eclipse would fall 120° to the westward in a part of the world that was not even known to exist. At its third return, however, the eclipse would fall in approximately the same longitude as it did 54 years before but several hundred miles north or south of its former position according to whether the series to which it belonged was moving northward or southward. By referring to past records of eclipses kept by the Chaldeans, it might be possible to foretell in a rough way that a certain eclipse of the sun would be total in some country or, possibly even, some city of the then known world on a certain date.

It was probably through a knowledge of the Saros and from

reference to such eclipse records that Thales was able to predict to the Ionians the eclipse which bears his name. This is probably the most famous of all past eclipses occurring as it did in the midst of a battle between the Lydians and the Medes, who were so overcome with terror at the sight that they ceased fighting and concluded a peace with was cemented with a double marriage. Herodotus, the Greek historian, in writing of this event states that Thales did predict even the year in which the eclipse occurred. We imagine, though, that Thales would not have been much of an astronomer even for that period if he were not able with the aid of the Saros to predict at least the day and even the approximate time of day when the eclipse would take place.

To predict with the high degree of accuracy required today the time and circumstances of eclipses of the sun, it is necessary to have the most accurate positions that can possibly be obtained of the sun and the moon, their parallaxes, or the apparent angular dimensions of the earth as it would appear at the distances of the two bodies, and an accurate knowledge of the shape and size of the earth taking into account its flattening at the poles and departure from a truly spherical form.

One of the most interesting and valuable books having to do with the prediction of eclipses that has been published in modern times is Oppolzer's Canon Der Finsternisse, which is based upon modern tables of the positions of sun and moon and which gives with considerable accuracy the astronomical elements of all eclipses past and future between the years 1208 B. C. and 2162 A. D., 13,200 in number, 8000 of the sun and 5,200 of the moon with 160 charts giving the approximate position of the tracks of important total and annular eclipses on the earth's surface. This truly monumental work is of the

highest value in fixing the chronological times of many important events in history that have been connected with the occurrence of eclipses and in giving an approximate location of the paths of future eclipses. As it was impossible to undertake the computation of more than three points for each curve, one at the center of the path giving the position of the shadow at noon and one at either end corresponding to sunrise and sunset, it was not always possible to obtain an accurate curve to represent the eclipse track. In some cases the paths have been found to be incorrectly placed in latitude to the extent of one hundred miles or more. Also certain errors in the lunar tables that were used introduced some additional small errors in the elements given and in the eclipse tracks yet for the purpose for which it was intended, namely to give a comprehensive survey of all series of eclipses as far back as twelve hundred years before Christ, and for nearly two hundred and fifty years to come, it has proved to be of the greatest value.

For the benefit of astronomers and others who wish to make scientific observations of eclipses and as a part of the routine work connected with the publication of the American Ephemeris and Nautical Almanac predictions of all eclipses of the sun and moon that occur each year are made by the Nautical Almanac Office of the U. S. Naval Observatory at Washington, D. C., a few years in advance. So we may say that the prediction of eclipses has become one of the duties of the national government and is no longer left to the option of individual astronomers. It is well that this is so for the computation of eclipses is an expensive and time-consuming piece of work that would be a burden upon private observatories if they had to undertake it.

As a result of an international agreement made in 1911

at Paris by representatives of some of the leading countries of the world, an exchange of astronomical computations between the Almanac Offices of these countries is now being made to avoid unnecessary and expensive duplication of work. Although each country, as before, publishes its own national Almanac or Year-book giving the positions of the sun, moon, planets, and stars and all important astronomical phenomena for each year, much of the work is now contributed by the astronomers of other countries in exchange for work of a similar nature. Under this agreement the Nautical Almanac Office at Washington now furnishes to England, France and some other countries of Europe the computations of all eclipses for each year as a part of its contribution. From the British Office it first receives in exchange the positions of the sun and moon for the entire year from which the data required in the computation of eclipses are obtained.

The eclipse predictions that are made by the Nautical Almanac Office at Washington are therefore used not only by our own country but by many of the leading countries of Europe as well.

VI

HOW ECLIPSES ARE PREDICTED

It would not be in keeping with the purpose of this book to enter into the mathematics of the eclipse problem. A consideration of the methods and formulas used in the prediction of eclipses would be a subject for a book in itself and would be of interest chiefly to the mathematician or astronomer who has to undertake the computation of eclipses. We will consider here only a few points connected with the prediction of eclipses that may be of general interest.

To compute a total eclipse of the moon is a comparatively simple matter. An experienced computer will perform all of the work necessary for the prediction of the times and circumstances in less than two working days of seven hours each. But to compute all the elements of a total solar or annular eclipse and find the latitude and longitude of all the positions needed for the chart, which shows the outline of the shadow on the earth's surface, is very far from being a simple matter. In order to reduce to a minimum all chances of error in the computation of eclipses it is the custom of the Nautical Almanac Office to have two computers work independently, and when possible, by different methods on the same eclipse.

The check computation of a total solar eclipse, which is a duplication of all the most important parts of the work and a close check on the remainder, takes anywhere from ninety to one hundred and twenty hours of close, exacting work while the original computation will take considerably longer. At least this has been the experience of the writer who has had

the privilege of making the check computations of all eclipses for the Nautical Almanac Office during the past fourteen years.

A large total solar or annular eclipse visible in equatorial regions will take longer to compute than a total solar or annular eclipse visible in mid-latitudes because all of the penumbral shadow, 4,000 miles or more in width, within which only the partial phase of the eclipse is visible, lies on the earth's surface. So the curves given on the charts are larger and there are more of them to compute. On the other hand, a partial solar eclipse, visible only in polar regions, for which there is no path of total eclipse to compute, can be disposed of in less than one-third of the time needed for a total solar or annular eclipse in equatorial regions.

A glance at a chart of a total solar eclipse published in the American Ephemeris will show that there are a number of curves giving the position of the shadow at different times. Most important of all is the path of total eclipse, never more than 170 miles wide, usually much less, and about 5,000 miles long, bounded by its northern and southern limiting curves, as they are called. These two limiting curves are the most troublesome and exacting of all curves to compute. The central line of the eclipse, midway between the limiting curves near which the scientific observer tries to locate, since here the duration of totality is longest, can be disposed of very easily by fairly simple computations. But the positions of two diametrically opposite points one on each of the limiting curves will take four or five times as long to compute, as the point on the central line half way between them. A point on the central line represents the position of the axis of the moon's shadow-cone at any instant but the two points, one on each of the limiting curves, are on the circumference of the

shadow at opposite ends of the diameter passing through the point on the central line. As the axis of the shadow traces the line of central eclipse over the surface of the earth, the points at the extremities of the diameter of the shadow trace out the northern and southern limiting curves of the path of total eclipse. One who is located within these limits will see a total eclipse of the sun with duration longest on the central line and shortest on the limiting curves. If the observer is just without these limiting curves only a partial eclipse will be seen, the magnitude of the partial phase decreasing with distance from the limiting curves of total eclipse at the rate of about five per cent. for every 250 miles.

In addition to the path of total eclipse a series of points must be computed for locating the limits of the partial phase of the eclipse outside of which no eclipse of the sun will be seen. Except in eclipses in equatorial regions only one of these limiting curves of the eclipse will fall on the earth's surface, the other falling off into space beyond one pole of the earth. Series of points must also be found for drawing curves showing where the eclipse begins at sunrise and where it ends at sunrise, as well as where the phase of the eclipse is greatest at sunrise. Corresponding curves must also be given for sunset. The first contact of the shadow with the earth will be at a point where the sun is rising and the last contact at a point where the sun is setting and the eclipse will occur with the sun on the meridian midway between the sunrise and sunset curves. The region enclosed by the sunrise and sunset curves and the limiting curves of partial eclipse will represent that portion of the earth's surface within which the eclipse will be observable.

All of the work of eclipse prediction is done about four years in advance and is then available, in the case of a total

eclipse, to all those who are planning expeditions to the path of totality. It speaks well for the exactness of modern astronomical calculations that the observer picks out his station with the greatest confidence, though it lie in a strip only a few miles wide, knowing that within a few seconds of the predicted time the shadow of the moon will pass over him.

If the earth would obligingly stand still during the three hours or so that the moon's shadow is sweeping over it and if it were as flat as the flat-earth theorists would like us to think it is, the computer of eclipses would find his problem greatly simplified. But as the shadow of the moon runs over the earth from west to east the observer is also being carried eastward by the rotation of the earth at a rate that varies according to his distance from the equator. The shadow of the earth overtakes and passes him. It is the computer's problem to find the trace of the rapidly moving lunar shadow over the rapidly rotating earth that is not even a perfect sphere but bulges at the equator and is flattened at the poles to an extent great enough to have an appreciable effect upon the position of the shadow path.

The computer attacks the difficulties of his problem by first finding the projection of the moon's shadow on a plane through the earth's center that is at right angles to the axis of the shadow-cone. This plane he refers to as the fundamental plane. Then by appropriate formulas he transfers the positions of the shadow in this plane to the rapidly rotating spheroidal surface of the earth.

How accurately, one may ask, can the times and circumstances of a solar eclipse be predicted? As far as the theory is concerned, the times of beginning and ending of a total solar eclipse can be computed as accurately as they can be observed, to a fraction of a second. These times are computed

to the nearest hundredth of a second and published to a tenth of a second yet everyone who has ever observed a total solar eclipse knows that the times may be, and usually are, "off" by a number of seconds, often as many as twenty or more. The trouble here is not with the eclipse theory nor the computer but with unknown, and so far unexplained, irregularities in the motion of the moon which produce discrepancies between its true position in the heavens and the positions predicted from the lunar tables, which are used in the computation of eclipses.

Though the moon is one of the smallest members of the solar system its position is the most difficult to predict and it has caused the astronomers as much trouble as all the rest of the satellites and planets combined.

The recent tables of the moon published in 1920 by Prof. E. W. Brown, one of the greatest mathematicians of the present time, represent years of painstaking work and research into that most difficult of all problems in theoretical astronomy, the motion of the moon. Yet the theory upon which the construction of these tables is based does not explain these small peculiarities in the moon's motion and Prof. Brown has expressed the opinion that there is something affecting the motion of the moon that cannot be explained by any existing theory of the moon's motion. For any other purpose except the computation of eclipses the position of the moon is known accurately enough. It wanders in general not more than twenty miles or so from its predicted position which is only about one-hundredth of its own diameter, an amount entirely inappreciable to the naked eye. That is, if two moons were in the heavens, one in the theoretical position computed from the tables and the other in the moon's true position they would appear to the naked eye as one, though with the aid

of a telescope a slight overlapping of the disks could be detected.

This discrepancy between the true and computed position of the moon, small though it is, is sufficient to introduce an error of a number of seconds in the predicted times of solar eclipses and an error of two or three miles in the position of the path of total eclipse. To correct this so far as possible it has become customary to find a few weeks or months in advance of eclipse day, just how much the true position of the moon is differing from the theoretical position. This is done by means of direct observations of the position of the moon in the heavens. The times and duration of the eclipse and the position of the path of total eclipse then receive small corrections to make them conform with the latest observations of the moon's position and these corrections are published for the benefit of those who are planning to make scientific observations within the path of total eclipse. For general purposes of observation and for the eclipse charts the corrections are too small to be appreciable.

It is the custom of the Nautical Almanac Office to publish a year or so in advance of the date of total solar eclipses visible in the United States a special eclipse pamphlet for the benefit of those who are planning to observe the eclipse. This gives, in addition to the information given in the American Ephemeris on the subject of the eclipse, the times and circumstances of the eclipse for a number of cities in the United States, as well as meteorological data on weather conditions at favorable points within the eclipse path and a large scale map of the eclipse path within the United States. This was done in the case of the eclipse of June 8, 1918, and the eclipse of January 24, 1925 visible in New York and New England.

VII

SOMETHING FOR THE FLAT-EARTH THEORISTS TO THINK ABOUT

The question of the shape of the earth was thrashed out pretty thoroughly some three centuries ago in the days of Galileo. Yet we still have with us the flat-earth theorists, so man-centered in their outlook that they still cling to the old "lanterns-hung-out-in-the-heavens-for-man's-benefit" style of universe with the earth the fixed and immovable center of all.

That the earth is spherical in shape and that it rotates on its axis and revolves around the sun are not self-evident facts. They require proof and it took some centuries to produce this proof.

There are today a number of independent ways of establishing the fact that the earth is a sphere, or to be more exact, a spheroid, slightly flattened at the poles and bulging at the equator. Yet the most convincing arguments are not the most easily understood and so we often read in school books that we know the earth is round because it has been circumnavigated. As a matter of fact we could circumnavigate a banana-shaped world or a pear-shaped world. A far more convincing argument is furnished by geodists or surveyors who have measured arcs of meridians,—of great length in some instances,—thus showing by direct measurement the spheroidal shape of the earth. Also, we often hear or read, as one proof of the earth's sphericity, that the earth throws a circular shadow over the moon at the time of lunar eclipse. As a matter of fact, though, the outline of the earth's shadow

on the moon is very hazy and ill-defined owing to the presence of an extensive atmosphere surrounding the earth which by refraction of sunlight into the earth's shadow-cone greatly blurs and dims the shadow outline. Then too a sphere is not the only body that will cast a circular shadow.

Many of the proofs of the earth's sphericity at our disposal today were not available in the time of Galileo but even with his crude telescope he was able to see four of the small moons of Jupiter revolving around the huge planet and the phases of Venus, which furnished a proof of its revolution around the sun. Here, then, were spherical bodies in the heavens that were not revolving around the earth, and by analogy one might reasonably conclude that the earth also was a spherical body in revolution about the sun. This form of reasoning does not appeal to the flat-earth theorists today any more than it did in the time of Galileo, though today the modern telescope adds abundantly to the meager evidence furnished by Galileo's 'optik tube.' Possibly the flat-earth theorists of the present day are like the learned man of three centuries ago who refused to look through the telescope of Galileo for fear he might see something to convince him!

There is no better proof of the fact that the earth is a rotating spheroid in revolution around the sun than that furnished by the results of the astronomical predictions of total solar eclipses when taken in connection with the fact that observations of eclipses within the shadow tracks have proven the predictions to be correct. This is a proof not generally given because it requires some knowledge of the manner in which solar eclipses are predicted to appreciate its force.

If our flat-earth theorists will procure some back numbers of the American Ephemeris for sixty years or more or some English Nautical Almanacs or copies of the Connaissance des

Chart showing tracks of some eclipses of the present century, past and future.

Temps of the French, going back, for their purpose, a hundred years or so, they will be impressed with the odd form of the tracks of total solar eclipses over the earth's surface. Their general characteristics are great length, frequently five thousand miles or over, extreme narrowness, being always under 170 miles and often less than 100 miles, and their peculiar curvature, particularly in high latitudes. Now for nearly one hundred years astronomers have been making scientific observations of total solar eclipses within these eclipse tracks. In some instances they have travelled half way around the world, when these tracks have fallen in out of the way places or over unavailable ocean expanses, in order to be within the eclipse path at the specified time. Often when the path has fallen in well-populated regions of the world the entire path of the eclipse has been thickly studded with observers scientific and otherwise. In the case of the total solar eclipse of July 29, 1878, which was visible in the United States and Canada, it has been said that observers were scattered so thickly along the path that it resembled one continual observatory, and fortunately, they were rewarded with perfect weather conditions at most stations and a glorious coronal display.

Any number of instances might be given of observations of total eclipses made at widely separated stations within the long, narrow, curved path of the moon's shadow, and in all this period covered by the scientific observation of total solar eclipses we find no record of failure on the part of the astronomers to correctly predict the course that would be followed by the shadow of the moon. The first American eclipse expedition, to Penobscot in October 1790 did, to be sure, find itself just without the path of total eclipse owing possibly to an error in the lunar tables then in use or to imperfections

in the methods of predicting the limiting curves of the eclipse. This rather strengthens the point we would make, however, as the astronomical elements and constants upon which the prediction of eclipse depend were not known to the same degree of accuracy in those days as they are at the present time, nor were as precise methods of computation employed.

Granted, then, that the paths of total solar eclipses are correctly computed and do represent the course of the moon's shadow over the face of the earth, how does that prove that the earth is round, that it rotates and that it revolves around the sun? We would suggest here that the doubter study in detail the fundamental theory and formulas upon which the prediction of eclipses rest but we may say briefly that the entire fabric of eclipse calculations rests upon assumptions as to the form and size of the earth, its distance from the sun and from the moon and the rate at which it is turning on its axis and revolving around the sun. If any of these assumptions were wrong the track of a total solar eclipse over the surface of the earth would not fall where the astronomer says it will fall.

Indeed the accuracy now obtainable in the calculation of solar eclipse paths may be taken as a proof of the correctness of some of the most fundamental conceptions of astronomy. If there were a mistake in the estimate of the size of the earth, sun, or moon, or of the relative motions and distances of these three bodies or even in the small amount of the flattening of the earth at the poles it would show up in the results of the eclipse calculations, in the position and width of the shadow track and in the times and duration of total eclipse.

It may well be considered one of the foremost achievements of astronomy of today that from theory alone the course of the moon's shadow over the face of the earth can be predicted

in advance with an error not exceeding three or four miles at most. It is expected that the cause of the slight discrepancies now existing between observations and theory and due to irregularities in the motion of the moon will in time be discovered and eliminated. If our flat-earth friends question the correctness of these fundamental assumptions upon which the prediction of eclipses rests let them try to predict eclipses upon the basis of their flat-earth theory!

VIII

PAST TOTAL SOLAR ECLIPSES IN THE EASTERN PART OF THE UNITED STATES

In the three hundred years and over that have elapsed since the Pilgrim fathers landed in New England, there have been but seven total eclipses of the sun visible in this part of our country.

These eclipses occurred respectively on November 14, 1659, August 22, 1672, July 12, 1684 (total-annular), January 19, 1768 (total-annular), June 24, 1778 and June 16, 1806. There have been in addition an equal number of annular eclipses of the sun visible in the same section.

The first total solar eclipse in the British colonies of which there is any record was the eclipse of June 24, 1778, a splendid eclipse of four minutes duration occurring near noontime. The path of this eclipse passed from Lower California across some of the southern states to the Middle Atlantic States and New England. After leaving the North American coast it crossed the Atlantic to Spain and thence to North Africa, where it left the earth at sunset.

David Rittenhouse of Philadelphia, one of the earliest of American astronomers, observed this eclipse, as did also Prof. Samuel Williams at Bradford, Mass. In writing of his observations, Prof. Williams says, "The dew fell so fast as to wet the paper we were using to a considerable degree." This eclipse was also observed at sea by the Spanish Admiral Don Antonio Ulloa, while passing from the Azores to Cape St.

Vincent. Ulloa evidently viewed the eclipse under a perfect sky for he made very complete observations for those days including a drawing of the corona which he refers to as a 'luminous ring,' the present name of corona being then unknown. He also records the appearance of the brighter stars and the effect of the eclipse upon members of the crew and animals on board, and describes an apparent 'hole' in the disk of the moon during eclipse which was doubtless a solar prominence. This eclipse may possibly have been visible in New York City though there is no record of observations being made there.

The next eclipse, that of October 21, 1780, came down from Baffin Land and Hudson Bay to the St. Lawrence River and Maine. It is of special interest because it was the first eclipse for which an American eclipse expedition was planned and sent out. Though it occurred during the Revolutionary War, the British garrison at Penobscot granted a request that an eclipse party be permitted to choose a suitable place in that vicinity for observing the eclipse. Consequently the Commonwealth of Massachusetts sent an expedition to Penobscot by vessel under the direction of Prof. Samuel Williams of Harvard. This expedition, unfortunately, failed to get quite within the path of totality, owing probably to inaccuracies in the tables giving the position of the moon; so only the phenomenon known later by the name of Baily's Beads was observed, the corona or 'luminous ring,' as it was then called, not being visible.

The next point of interest in the history of eclipse observations in New England was the observation of the annular eclipse of April 3, 1791, by Prof. Webber at Harvard. The sky was perfectly clear and the annulus was observed for

nearly five minutes. Prof. Webber records the predicament he was in as a result of his clock stopping the day before the eclipse and the goodness of the President of the University, whose clock had not played such an unkind trick at a critical time, in asking him to observe the eclipse with him.

The eclipse of June 16, 1806, the last total solar eclipse to be observed in this part of the country, up to the present time, was a fine eclipse of more than four and a half minutes duration, which is considerably more than the average length of totality. It also occurred near noon and was total at Ogdensburg, Albany, and Kinderhook, N. Y., and Salem, Mass. DeWitt observed the total phase of the eclipse at Albany for about four minutes and fifty seconds, the Spanish astronomer Don Joaquin Ferrer for four minutes thirty-seven seconds at Kinderhook, near the Hudson, and the well-known astronomer Bowditch recorded his observations at Salem, Mass. Of the appearance of the corona he says simply, "The whole of the moon was then seen surrounded by a luminous appearance of considerable extent such as has generally been taken notice of in total eclipses of the sun." Indeed little is said regarding the corona until the occurrence of the total eclipse of July 8, 1842, which was observed in one of the most thickly populated parts of Europe and which may be said to have ushered in the period of the New Astronomy. Several observers recorded the appearance of the corona several seconds before the beginning of totality, an unusual occurrence, and the fact began to be recognized that it was a solar appendage of peculiar interest and scientific importance.

The eclipse of 1806 was the last total solar eclipse to visit the northeastern part of the United States up to the present time. The eclipse of May 28, 1900 was total in the southern

states from New Orleans through Georgia to North Carolina and Norfolk, Va., but it was only a large partial eclipse in Pennsylvania, New York and New England. Although the duration of this eclipse was less than two minutes in the United States there were many expeditions in the field and it was one of the most successfully observed eclipses of recent years.

IX

THE TOTAL SOLAR ECLIPSE OF JANUARY 24, 1925

AFTER an interval of nearly one hundred and twenty years, on the twenty-fourth of January, 1925, the path of a total eclipse of the sun will pass once more over the northeastern section of the United States. Up to this time there has been no total eclipse of the sun visible in New York, Pennsylvania, or New England since June 16, 1806 and not until the year 2024 will another total eclipse be visible in the same part of the United States. The sun may rise eclipsed at Boston on October 2, 1959 but the path of the eclipse will then pass off to sea.

The path of the eclipse of next January will first strike the earth in Minnesota at sunrise a little to the east of Red Lake. From here it will pass in a southeasterly direction over the Great Lakes, northern Minnesota, Wisconsin, Michigan, a small section of Canada, to Niagara Falls and Buffalo, N. Y. The total phase of the eclipse will begin here shortly after nine o'clock in the morning, Eastern Standard Time, with the sun about 13° above the horizon. The path of totality will pass from Buffalo in a southeasterly direction, to that part of the Atlantic coast which lies between New York City and the extreme southern part of Massachusetts, in a strip about one hundred miles wide and over four hundred miles long across the most densely populated part of the United States. Including New York City, which lies on the southern limit of the eclipse, with the harbor, Battery and lower part of the city, just without the path, and the northern part of the city

within it, there will be approximately ten million people within the path of total eclipse not including the number that will come to the path from points outside.

The central line of the eclipse, the trace of the axis of the moon's shadow-cone across the earth's surface, will pass almost directly over Buffalo, Watkins, at the head of Seneca Lake, and Binghamton. It will cross the Hudson River at a point between Newburgh and Poughkeepsie and pass over Danbury and New Haven, Conn. to Gardiners Island and Montauk Point.

As the shortest distance from the central line to the northern or southern limit of the path of total eclipse is about fifty-one or fifty-two miles all points within this distance of the central line on either side will be within the path of total eclipse.

The northern limit of the eclipse will pass from a point in Wayne Co., N. Y. on Lake Ontario to a point about six miles south of Syracuse, and about five or six miles south of Morrisville and Cooperstown, N. Y., striking the Hudson about twenty-two miles south of Albany. It will cross the southwestern part of Massachusetts passing about two miles south of Springfield, Mass., to the extreme northeastern corner of Connecticut, and directly through Rhode Island to a point less than two miles south of Providence. It then passes through the extreme southern part of Massachusetts less than five miles north of Fall River and New Bedford to a point on Nantucket Sound, a few miles southwest of Barnstable on Cape Cod.

The southern limit of the path of total eclipse passes from a point on Lake Erie six miles north of Mayville, N. Y., across the extreme southwestern corner of New York State to Pennsylvania running about five miles south of Wellsboro, Penn.,

and about an equal distance north of Wilkes-Barre. Morristown and Newark, N. J., lie about eight miles outside of the southern limit and Paterson and Hackensack, N. J. about an equal distance within the limit. The northern part of Jersey City lies directly on the southern limit of totality and Brooklyn and Jamaica, Long Island, just outside. Mineola, L. I. will be about five miles within the southern limit.

After leaving Long Island and the New England Coast, the path of total eclipse crosses the North Atlantic in a northeasterly direction. The eclipse will occur at noon at a point in approximately 44 west longitude and 42 north latitude, and it will pass off the earth at sunset at a point between the Shetland and Faroe Islands. Following the discouraging practice of eclipse paths in general it wastes, from the point of view of the astronomer, the best part of its path in mid-ocean since it does not touch land once after leaving Nantucket on the New England coast. The longest duration of the eclipse will occur near the middle of its path in the Atlantic ocean where the sun is at its highest altitude above the horizon. The longest duration in the United States will be on the central line on the New England coast. The most favorable points for observation should be on the Hudson and in Connecticut in the vicinity of New Haven. As the duration of totality always decreases with distance from the central line it is advisable that those who wish to observe the eclipse should get well within the path of totality. Also, as explained in an earlier chapter, uncertainties in the moon's position make the exact position of the northern and southern limits doubtful to the extent of two or three miles. As the corona cannot be seen so long as the least percentage of sunlight remains and as the glory of the eclipse lies in the corona, it is advisable for this reason alone to get within the northern and southern

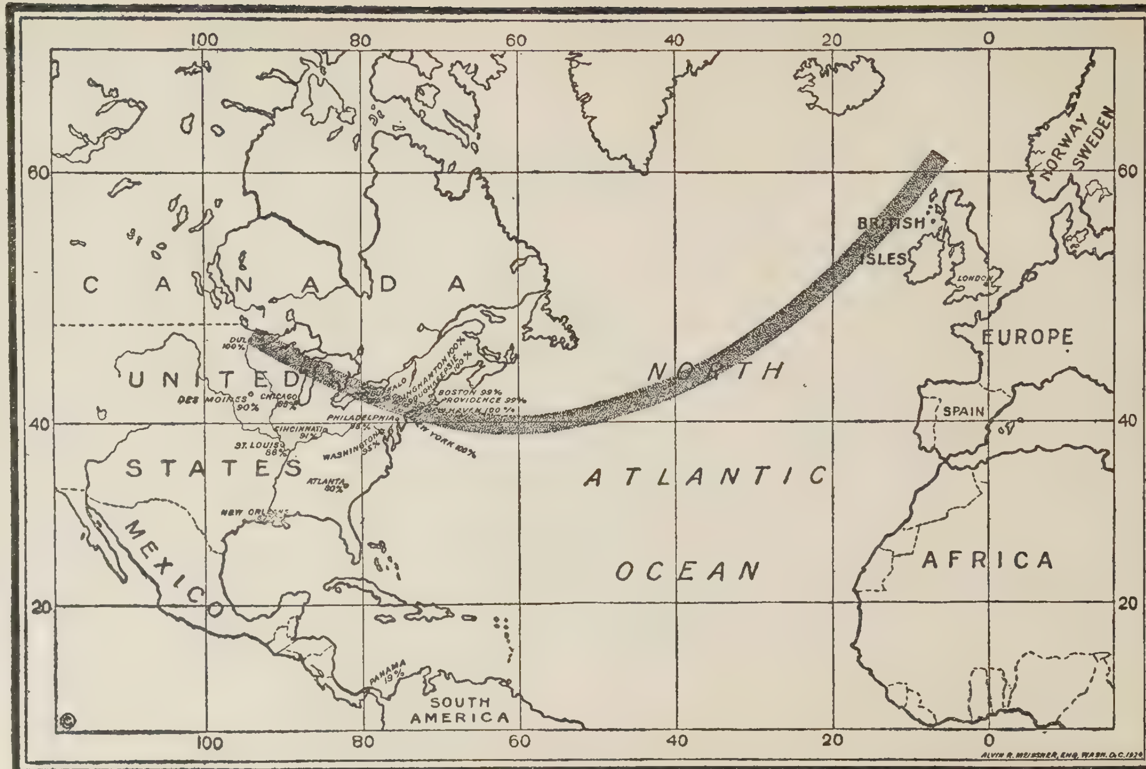


Chart showing path of Total Solar Eclipse of January 24, 1925.

limits by a safe margin of at least ten miles. In the western part of New York the sun will be at such a low altitude that it will be essential to choose a point of observation commanding an unobstructed view of the southeastern horizon. At Duluth, Minn., the altitude of the sun will be only 2° at the time of total eclipse and no observations of any scientific value can be expected west of New York State or possibly Toronto in Canada. In the vicinity of the Hudson River, and in Connecticut, the sun will be at an altitude of nearly 20° so the conditions should be more favorable in this section. It is also advisable to choose, if possible, an observing station at a considerable elevation above the surrounding country. This is imperative if one wishes to watch for the approach of the moon's shadow which sweeps down from the west with the frightful velocity of half a mile a second. This is one of the most impressive features of the eclipse but one that is rarely observed. Here aviators have the advantage over all other observers. Indeed when it comes to viewing a total eclipse as a scenic feature, the aviator is at a most decided advantage for he can in general rise above low-lying fogs and clouds and be fairly certain of an unobstructed view. Like the man aboard ship, however, he is at a disadvantage when it comes to making scientific observations with telescope and spectroscope for here a firm foundation and mounting for the instruments is of prime importance.

It may seem to the general reader that it would be impossible to make observations of great scientific value in such a brief period as one and a half minutes. Yet it may be recalled that the eclipse of June 8, 1918 that was so successfully observed by expeditions from the Lick, Yerkes and United States Naval Observatory parties in points in Oregon, Washington, and Colorado, had a maximum duration of less than two minutes.

Also one of the most successfully observed eclipses and one of which the most complete records have been obtained was the eclipse which occurred on New Year's Day 1889. The path of totality of this eclipse ran across the North American continent from California to Manitoba, and the sky was clear practically everywhere. Though the duration of this eclipse was less than two minutes in the United States, a wealth of drawings and photographs were obtained and many additional scientific observations were made at a large number of stations. So we may say that the briefness of the eclipse alone will not prevent the astronomers from securing many valuable observations provided the skies are clear at even one or two stations, during the few critical moments. Of greater concern to the astronomer is the fact that the coming eclipse will occur at an unfavorable time of day when the sun is not far above the horizon and at an unfavorable time of year when stormy weather is most general. Yet when it comes to considering weather conditions, a passing cloud on a summer's day or a sudden shower in spring might prove to be just as fatal as a snow storm in winter. The weather has played odd jokes on eclipse expeditions in the past, often when and where least expected, as in the eclipse of Sept. 10, 1923 when fair weather occurred in Mexico, where it was least expected, and the sky was heavily overcast with clouds where most favorable weather conditions had been promised, in Lower California.

A most interesting feature of the coming eclipse, unique in the history of eclipse observations is the fact that ten observatories will lie directly within the path of total eclipse while there will be thirteen more within less than fifty miles of the northern and southern limits of the eclipse. The observatories within the path include the observatory of the

University of Toronto, in Canada, Fuertes Observatory, Cornell University, Ithaca, N. Y., Smith Observatory, Geneva, N. Y., Elmira College Observatory, Elmira, N. Y., Observatory of the Bausch and Lomb Optical Co., Rochester, N. Y., Columbia University, New York City, Vassar College Observatory, Poughkeepsie, N. Y., Wesleyan University Observatory, Middletown, Conn., Yale University Observatory, New Haven, Conn., and Maria Mitchell Observatory, Nantucket.

The thirteen observatories within less than fifty miles of the limits of the path of total eclipse where there will be an eclipse of 99% or more are at Albany, N. Y., Amherst, Mass., Cambridge, Mass., Clinton, N. Y., New Brunswick, N. J., Northampton, Mass., Princeton, N. J., Providence, R. I., South Bethlehem, Penn., South Hadley, Mass., Syracuse, N. Y., Wellesley, Mass. and Williamstown, Mass. The Sproul Observatory of Swarthmore College which sent an expedition to Mexico to observe the 1923 eclipse, will be about 75 miles from the southern limit of the eclipse path and the magnitude of the eclipse will be 98% at that point.

A partial eclipse of 95% or more will occur at some of the largest cities in the United States including Chicago, Philadelphia, Boston, Baltimore, Washington, Pittsburgh, Cleveland, Detroit, Toledo, Albany, and Ottawa and Montreal in Canada. In general there will be a decrease of about one per cent in the magnitude of the eclipse for every forty miles in distance from the northern or southern limit of the path of total eclipse, so the magnitude of the eclipse at any point outside the path of totality can be estimated approximately by measuring its distance from the nearest limit of the path.

The popular interest in the eclipse will be great owing to the fact that there will be no other total solar eclipse visible in this section for nearly one hundred years to come and the

scientific interest will be keen because of the large number of observatories and scientific institutions that lie within or close to the path of the eclipse. Here at last the astronomers have an eclipse that may not, it is true, offer as favorable circumstances as might be desired, but which will, nevertheless, knock at their very doors. Let it be hoped that the weatherman will not fail to provide a suitable setting for the scene.

CIRCUMSTANCES OF THE TOTAL SOLAR ECLIPSE OF JANUARY 24, 1925 FOR SOME OF THE PRINCIPAL TOWNS WITHIN THE LIMITS OF THE ECLIPSE.

1. Principal Towns Within the Path of Total Eclipse.

	Beginning of Partial Phase	Mid-Totality	End of Partial Phase	Duration
Duluth, Minn.*	. ..	8 h 0 m	9 h 9 m	0.5 m
Hamilton, Canada	7 h 59 m E.S.T.	9 6	10 21	1.8
Toronto, Canada	7 59 "	9 7	10 22	1.0
Buffalo, N. Y.	7 59 "	9 7	10 22	1.8
Ithaca, N. Y.	8 0 "	9 10	10 26	1.8
Geneva, N. Y.	8 0 "	9 10	10 26	1.8
Binghamton, N. Y.	8 0 "	9 11	10 27	1.8
Poughkeepsie, N. Y.	8 1 "	9 12	10 30	1.9
New York, N. Y.	8 0 "	9 11	10 29	0.5
New Haven, Conn.	8 1 "	9 13	10 32	2.0

Circumstances of the Total Solar Eclipse of Jan. 24, 1925 for Some of the Principal Towns Within the Limits of the Eclipse.—Continued.

2. Principal Towns for Which the Greatest Eclipse Is Ninety-five Per Cent. or Over.

	Beginning of Partial Eclipse	Greatest Eclipse	End of Partial Eclipse	Magnitude	Distance to Nearest Edge of Path
Albany, N. Y.	8 h 2 m E.S.T.	9 h 13 m	10h 31 m	99%	22 mi.
Augusta, Me.	8 8 "	9 21	10 41	96	200
Baltimore, Md.	7 56 "	9 5	10 23	96	150
Boston, Mass.	8 4 "	9 17	10 36	99	45
Cleveland, Ohio.	6 55 C.S.T.	8 3 C.S.T.	9 17	97	100
Chicago, Ill.*	.. ..	7 58 "	9 9	95	200
Detroit, Mich.*	.. ..	8 3 "	9 16	98	75
Harrisburg, Pa.	7 57 E.S.T.	9 6 E.S.T.	10 24	98	85
Lansing, Mich.*	.. ..	8 0 C.S.T.	9 13	98	80
Madison, Wis.*	.. ..	7 58 "	9 8	95	165
Minneapolis, Minn.*	.. ..	7 58 "	9 6	96	135
Montreal, Canada	8 6 E.S.T.	9 15 E.S.T.	10 34	95	235
Newark, N. J.	8 0 "	9 11 "	10 29	99+	5
Ottawa, Canada	8 5 "	9 14 "	10 30	96	190
Pittsburgh, Pa.	7 55 "	9 3 "	10 18	96	160
Philadelphia, Pa.	7 58 "	9 8 "	10 26	98+	80
Providence, R. I.	8 3 "	9 15 "	10 35	99+	2
Toledo, Ohio.*	.. ..	8 2 C.S.T.	9 14	96	125
Trenton, N. J.	7 58 "	9 8 E.S.T.	10 27	99	50
Saginaw, Mich.*	.. ..	8 2 C.S.T.	9 16	99+	20
Springfield, Mass.	8 2 "	9 14 E.S.T.	10 33	99+	2
Syracuse, N. Y.	8 1 "	9 11 "	10 27	99+	8
Washington, D. C.	7 55 "	9 4 "	10 22	95	190

Circumstances of the Total Solar Eclipse of Jan. 24, 1925 for Some of the Principal Towns Within the Limits of the Eclipse.—Continued.

3. Principal Towns for Which the Greatest Partial Eclipse Is Less Than Ninety-five Per Cent.

	Beginning of Partial Eclipse	Greatest Eclipse	End of Partial Eclipse	Magnitude
Atlanta, Ga.	6 h 46 m C.S.T.	7 h 50 m C.S.T.	9 h 3 m C.S.T.	80 %
Austin, Tex.*	.. ..	7 38 "	8 38 "	61
Bismark, N. D.†	.. ..	.. ..	9 1 "	(59)
Cheyenne, Wyo.†	.. ..	.. ..	7 49 M.T.	(41)
Cincinnati, Ohio	6 51 "	7 57 "	9 10 C.S.T.	91
Columbia, S. C.	6 47 "	7 54 "	9 9 "	83
Columbus, Ohio.	6 53 "	7 59 "	9 13 "	94
Denver, Colo.†	.. ..	.. ..	7 47 M.T.	(41)
Des Moines, Iowa.*	.. ..	7 53 "	9 1 C.S.T.	90
Kansas City, Mo.*	.. ..	7 h 49 m "	8 h 56 m "	84
New Orleans, La.*	.. ..	7 42 "	8 48 "	67
Omaha, Neb.*	.. ..	7 51 "	8 58 "	87
Raleigh, N. C.	7 h 50 m E.S.T.	8 59 E.S.T.	10 15 E.S.T.	88
Santa Fe, N. Mex.†	.. ..	.. ..	7 40 M.T.	(36)
Springfield, Ill.*	.. ..	7 53 C.S.T.	9 3 C.S.T.	89
St. Louis, Mo.*	.. ..	7 51 "	9 1 "	86

*Sun Rises Partially Eclipsed.

†Greatest Eclipse Takes Place With Sun Below the Horizon.

X

THE PARTIAL SOLAR ECLIPSE

The first stage of a solar eclipse begins when the edge or rim of the moon, 'limb' the astronomer calls it,—first comes into contact with the edge of the sun. Needless to say this contact is apparent only, for the moon is nearly ninety-three million miles this side of the sun and the only reason that it can hide a body four hundred times greater than itself in diameter is because it is four hundred times nearer.

If you chance to be near an eclipse camp somewhere within the belt of totality when the partial phase of the eclipse begins you will hear some astronomer who is looking through a telescope call out 'first contact' and you will know the eclipse is 'on.' More than an hour later, usually, 'second contact' will take place when the sun is completely covered by the moon and the total phase of the eclipse begins. 'Third' and 'last' contact will follow in turn with the ending of totality and the ending of the partial eclipse.

If you don't happen to be near an astronomer or someone who is in possession of a telescope at the time of first contact the chances are that you will not know the eclipse has begun until the moon has notched a considerable piece out of the western rim of the sun. It is not easy to tell just when the lunar disk first touches that of the sun and the eclipse starts, even if you are looking through a telescope, for, obviously, you cannot see the moon until its dark rim is visible against the luminous surface of the sun and then the eclipse has already started. The times of first and last contact of sun

and moon are of no scientific value because they cannot be determined to any great degree of accuracy. The times of second and third contact which are the times of beginning and ending of totality can be observed to a very high degree of accuracy, however, because of the nature of the phenomena that attend them, and they are of very considerable scientific value since they furnish a means of comparing the true and predicted positions of the moon at a given time, which gives a check on the accuracy of the tables of the moon used in predicting eclipses as well as a means for improving these tables.

If you are outside the belt of total eclipse the partial phase of the eclipse is all that you are going to see and this is of no scientific interest and of little general interest unless the magnitude is at least 95%. Of course the nearer you are to the belt of totality the larger and more interesting the partial phase will be but after all it is the total phase and its unique and impressive phenomena that everyone wants to see and if you are a few miles *outside* the path you will find that it will be well worth while to put yourself a few miles *inside* of it.

After the first contact there is little to watch during the partial phase except the slow and gradual encroachment of the moon upon the solar disk and a slow and gradual decrease in the light of the sun up to the time of greatest obscuration. The magnitude of the greatest eclipse will vary inversely with the distance of the observer from the central line of total eclipse. At a distance of two thousand two hundred miles or so from the central line the eclipse will not be much more than a mere grazing contact of sun and moon. By magnitude of the eclipse for any place we mean the per cent of the *sun's diameter* that is covered at greatest obscuration by the moon and not the per cent of *solar surface* that is covered as appears to be quite generally believed. For example, if you read that

a certain solar eclipse will have a magnitude of 75% at your city that means that 75% of the sun's diameter will be covered at greatest eclipse at that place and not 75% of the surface.

After greatest obscuration occurs at any place the moon is observed to recede slowly from the solar disk, last contact taking place at the eastern edge of the sun since the moon crosses the face of the sun from west to east.

If the partial eclipse is large, say over 90%, the solar crescent at time of greatest eclipse will be very thin and as a result the light will be reduced to a sort of weird twilight, only stronger than twilight in its intensity. The landscape will take on a peculiar hue and the image of the sun wherever it is formed will be noticeably crescent-shaped. This has been particularly noted in the case of sunlight sifting through the interstices between leaves on trees or hedges, the images falling on the ground in the form of series of crescents presenting a weird and unnatural effect. The writer recalls that when at recitation class in mathematics at Cornell University, Ithaca, N. Y., during the maximum obscuration at that point of the eclipse May 28, 1900, total at Norfolk, Va. several hundred miles away, the Professor who was conducting the class turned the seat of a cane-bottomed chair with its regular rows of circular openings toward the sun so that a series of images of the thin solar crescent fell in rows and columns on the floor. There are many ways in which images of the solar crescent can be formed, one way being to turn a pair of binoculars toward the sun and focus the image on a sheet of white paper or cardboard, held a foot or so from the eye-end. Care should always be taken not to look directly toward the sun either with the naked eye or through binoculars or telescope without using a dark glass cap or smoked glass. If this

precaution is not taken serious injury to the eyes or blindness may result.

The time of last contact can be determined more accurately than the time of first contact because the dark rim of the moon can be followed to the point of disappearance more readily than it can be discovered at the instant of first contact. The entire duration of the partial eclipse will vary for different points. It will be longest at points close to the limits of total eclipse where the eclipse is greatest and extremely short at points near the outer limits of the penumbral shadow, as it is called, within which only partial phases of the eclipse are visible. For example, in the case of the total solar eclipse of January 24, 1925, the entire duration of the partial eclipse at Albany, N. Y., a little over twenty miles outside the northern limit of total eclipse, where the magnitude is 99%, is two hours twenty-nine minutes, while at Panama over two thousand miles away where the magnitude is 19% the duration of partial eclipse is one hour twenty-six minutes.

If weather conditions are fair along the northern and southern limits of the path of total eclipse during the eclipse of January 24, 1925 an excellent opportunity will be afforded to determine how close the predicted positions of these curves agree with the true positions. These limits will pass over or close to some of the largest cities in the country including New York City, and Syracuse, N. Y., Wilkes-Barre, Pa., and Springfield, Mass. and Providence, R. I. As we will see in the next chapter, it is possible to tell by the nature of the phenomena observed whether the station is within the path of totality or just outside and for the first time in the history of eclipse observations it may be possible to tell as a result of observations made by those located close to the predicted positions of these curves, how much the predicted positions are

in error as a result of uncertainties in the position of the moon. The astronomer interested in the scientific problems that are associated only with total eclipse is not going to lose the opportunity of making valuable observations by taking a station dangerously close to the limits of the belt of totality. Here is a chance, then, for the general observer who happens to be located close to the limiting curves to aid in the location of the exact limits of total eclipse by recording the phenomena that he observes during the maximum phase of the eclipse at his station. New York City will be a particularly favorable location for observations of this kind owing to the fact that the predicted southern limit passes directly through the down town section. Here, then, is an opportunity to check up on the accuracy of a predicted eclipse curve! If the moon is keeping no better to its prescribed path at eclipse time than it has been in the habit of doing in the past few decades, it is safe to predict that the calculated limits of total eclipse may be 'off' as much as three miles or so from the true positions.

By observations made in the vicinity of these curves it will be possible to tell how much the predicted positions are in error. How much the predicted times of the beginning and ending of total eclipse are in error will be known when the times of second and third contact are recorded by observers stationed within the belt of total eclipse. In extreme cases these have been found to be in error by nearly as much as thirty seconds.

XI

SHADOW BANDS

Shortly before the beginning of total eclipse, usually five minutes or less, faint, shimmering, wave-like bands of light and shade known as shadow bands are frequently seen flitting over the ground or sides of buildings. Records of the observations of these shadow bands are often very contradictory even when the observers of the phenomenon are at the same place. Some may see them while others do not. At some eclipses they are very conspicuous, at other sclipses they will be very faint or indistinct or not visible at all. They are usually, but not always, seen just after, as well as just before, total eclipse.

The shadow bands vary in width and velocity as well as in distinctness but they usually move very slowly, in general about six or eight miles an hour, and the direction in which they are moving seems to be the same as the direction in which the shadow-cone is moving. Their slow motion shows that they do not accompany the shadow-cone which moves across the earth with an average velocity of about twenty-five miles a minute.

The cause of the shadow bands seems to lie in the atmosphere of the earth itself, that is, they are believed to be a meteorological effect produced either by irregularities in the refraction of the light from the rapidly dwindling crescent of sunlight or due possibly to changes in the density of the air following the sudden drop in temperature at this phase of the eclipse. There is much that is peculiar in the behavior of

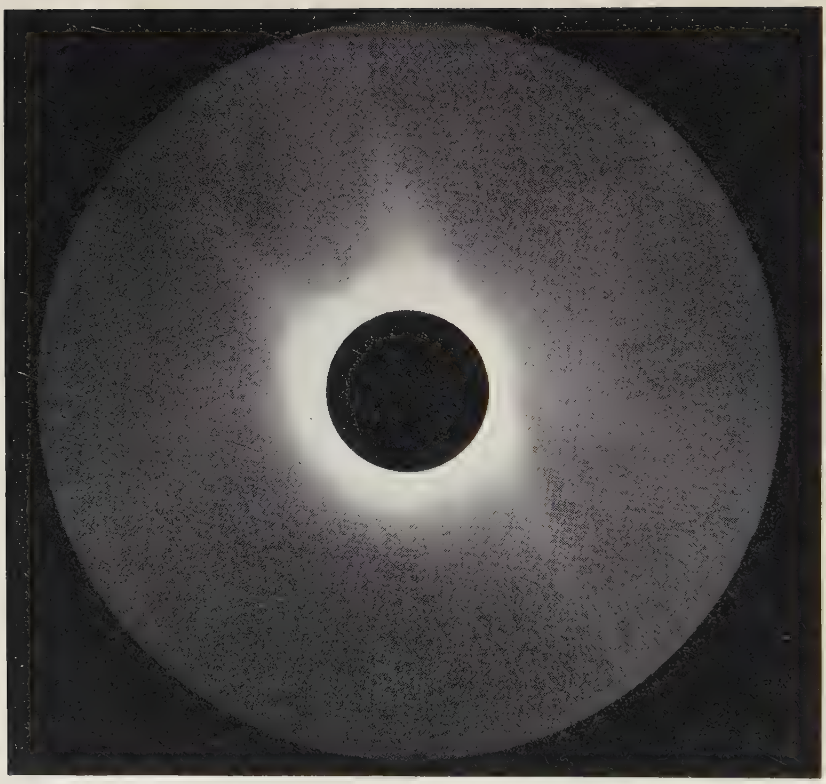
the shadowbands, however, and it cannot be certain that the above explanation is the true one until the phenomenon has been more generally observed and if possible, photographed.

Up to the present time all efforts to photograph the shadow bands have been unsuccessful. So here is an opportunity for someone to accomplish a difficult photographic feat. The co-operation of the general observer in the observation of shadow bands is always welcomed by the astronomer who is so occupied with observations connected with the total phase of the eclipse, which begin at nearly the same time, that he has little opportunity to study this interesting phenomenon which belongs in the field of meteorology rather than astronomy.

The best way to observe the shadow bands is to stretch a large sheet on the ground and as soon as the bands appear, a few moments before totality, note the time of appearance, and then the general direction in which they are moving by laying a rod on the sheet parallel to the direction of motion. Leave the rod lying in the position placed until after the end of totality when the direction can be determined at leisure. Also have a second sheet prepared to observe the phenomenon just after totality, if it should appear. Estimate the width of the bands and the distance between crests of the waves, how fast they are moving and whether they come singly or in groups.

The great difficulty in photographing the shadow bands lies in the fact that the general illumination is very faint at this time while the bands are wavy, indistinct and shimmering in their effect, much like the reflection of sunlight from rippling water. A highly sensitive film and the highest photographic skill will be required to catch them.

Some attention has been given to the problem of photographing the shadow bands in the research laboratories of



The Solar Corona photograph by Lick-Crocker Eclipse Expedition, Wallal, Australia, September 21, 1922.

the Eastman Kodak Co., and Dr. L. E. Jewell of that company has found that an extremely rapid combination could be obtained by using in succession some "gun-sight" achromatic lenses.

The Yerkes Observatory Eclipse Expedition which was stationed on Catalina Island to observe the total solar eclipse of September 10, 1923 planned to attempt the photography of the shadow bands with a set of three such lenses using a "Hurricane" plate and an exposure of one-hundredth of a second. Unfortunately these plans as well as many other eclipse plans were defeated by cloudy skies. It is to be hoped that the coming eclipse of January 24, 1925, will present a favorable opportunity for photographing the shadow bands, particularly as the path of totality will pass directly over the research laboratories of the Eastman Kodak Co. at Rochester, N. Y. where if anywhere, success should be attained in photographing this elusive phenomenon. It is possible that a movie camera fitted with a film of superspeed could also be used successfully for this purpose.

To show how differently the shadow bands may appear to two observers both skilled in making astronomical observations and stationed, moreover, at the same point we are quoting below from the descriptions of the shadow bands given by Mr. A. D. Ross, Professor of Astronomy and Physics in the University of Western Australia, who was a volunteer member of the Crocker Eclipse Expedition of the Lick Observatory to Wallal, Australia to observe the total solar eclipse of September 21, 1922, and Professor J. L. Chant of the Toronto Eclipse Expedition, who also observed the shadow bands at the same time and place. These excellent descriptions of the shadow bands will also give the general reader an idea of the manner in which this interesting phenomenon is observed and

what he may expect to see, if he is fortunate enough to be within the path of totality.

The following is taken from the description of the shadow bands by Professor Chant appearing in the Journal of the Royal Astronomical, Nov.-Dec., 1923.

"Suddenly, and before I had expected it, the shimmering, elusive, wave-like shadows began to sweep over me and the sheet. I grasped the rod and moved it back and forth until it was parallel to the crests of the waves as they moved forward. At the same time I began counting seconds—'one-and, two-and, three-and, etc.'—and I continued counting up to 150 before totality was announced. I think perhaps I counted a little too rapidly and, allowing for that, I judge that the bands began approximately 2¼ minutes before totality. They continued to move over me for only a short time, perhaps ten seconds, and then they were gone! They were faint, thrilling, ghost-like, but definite enough for me to be sure that I had seen the shadow bands. . . . . . . "I took my position at the second sheet to watch for the shadow-bands again. They began at 15 seconds after totality and to my surprise they seemed to come from the opposite direction. They were even fainter than at the beginning and lasted perhaps five seconds. I moved the second rod until I judged it was parallel to the crest of the waves.

"At the beginning of totality the bands came from west to east, moving in the same direction as did the moon's shadow as it swept across the earth; at the end they moved in the opposite direction, or so it seemed to me."

The following account of the same phenomenon as observed by Dr. A. D. Ross at the same place is taken from the Publications of the Astronomical Society of the Pacific for Feb., 1923.

SHADOW BANDS

I took up a position beside a horizontal white sheet about 1 minute 15 seconds before totality, and was at once conscious that the phenomenon was present. There was a shimmering effect over the entire sheet, which at once suggested the shimmering of objects seen over a stretch of highly heated ground. While it was impossible at the time to isolate individual bands or to note the onward motion (if any), I felt convinced that the length of the bands (the wave front) lay slightly east of north to slightly west of south. The distinctness (or rather indistinctness) of the shadings fluctuated slightly for 15 or 20 seconds, and then I observed that there were narrow dark lines (about an inch wide) at distances of a foot or so and that these had an easterly motion.

Between 1 minute and 40 seconds before totality the bands underwent a decided development. The narrow dark lines first acquired a penumbral fringe on each side, and then became reduced in intensity until the dark band was about 6 inches wide and showed only a slight darkening towards the central part. The bands were always rather indistinct and unstable in character, but the most persistent type was the 6-inch band described above with a wave-length (crest to crest) of about 16 inches. The average speed would be over 6 miles per hour.

A plate was exposed 30 seconds before totality, but it was impossible to record photographically such slight variations in shade in faint light.

About this time I noticed that the bands were traveling in groups and I had just made up my mind that there were about 8 in a group, when the next group certainly contained 10 or

11. The division between two groups would be less than that produced by omitting one band.

The bands were still visible 20 seconds before totality when I had to leave for other observations. No observations were made by me after totality.

It will be noticed that Prof. Chant observed the shadow bands about two minutes and a quarter before totality was called but that he saw them "for only a short time, perhaps ten seconds and then they were gone." Dr. Ross, on the other hand did not begin to look for the shadow bands until "about one minute and fifteen seconds before totality and was at once conscious that the phenomenon was present" and it was still present twenty seconds before totality when he was called away.

It would appear from these observations that the shadow bands are affected by the condition of the atmosphere in the immediate vicinity of the observer. This might account for the many contradictory reports as to the nature of the shadow bands that are so generally given. It is certain that the descriptions of the shadow bands usually are conflicting which add to the difficulties of giving a satisfactory explanation of their cause and origin. There are still a number of points regarding the appearance of the shadow bands that need to be cleared up and photographs of the phenomenon would be very helpful especially if a number of them could be obtained both at the same and different points of observation.

Shadow bands have been observed at annular eclipses as well as before and after total solar eclipses.

XII

BAILY'S BEADS

A FEW seconds before the beginning of total eclipse the rapidly dwindling solar crescent, which has become a mere thread of light by this time, may be seen to break up suddenly into beads of light, rounded or oblong in shape. The generally accepted explanation of this odd and beautiful effect, and beyond doubt the correct one, is that at this stage of the eclipse the rough and irregular edge of the moon covers the edge of the solar disk completely at some points while it just falls short of covering it at other points. In other words we see the sunlight coming through the valleys and depressions at the edge of the moon while the highlands and mountains cover the solar disk at adjacent points. The same effect will be seen at the end of the total phase of the eclipse at the opposite or western edge of the sun when the moon first uncovers it.

Baily's Beads received their name from Sir Francis Baily, who described this phenomenon in detail after observing it at the time of the annular eclipse of May 15, 1836, which passed over the northern part of England and the southern part of Scotland. His paper on the subject entitled "On a Remarkable Phenomenon that Occurs in Total and Annular Eclipses of the Sun" was presented in December of that year at a meeting of the Royal Astronomical Society, of which he was then Vice-President. Not only are the beads observed at annular as well as at total eclipses but they may also be seen at large partial solar eclipses when the observer is just outside of the belt of total or annular eclipse. They were seen under such circumstances by the members of the first American

eclipse expedition stationed near Penobscot in October, 1790, when this party just failed to get within the belt of totality. Under fair weather conditions they should be seen at all points just outside of as well as within the path of the total solar eclipse of January 24, 1925, which passes over such a thickly populated part of this country.

The first mention of the phenomenon later to be known by the name of Baily's Beads was by Sir Edmund Halley, of comet fame, who observed it at the time of the total solar eclipse of May 3, 1715, which was the last total solar eclipse visible in London.

The first photograph of Baily's Beads was made at Ottumwa, Iowa, by a section of the Philadelphia Photographic Corps under Prof. C. F. Hines of Dickinson's College, Carlisle, Pa., at the time of the total solar eclipse of August 7, 1869. The path of this eclipse crossed the American continent diagonally from Behring's Strait to North Carolina, passing over the states of Iowa, Illinois, Indiana and Kentucky. Later at the eclipse which occurred on New Year's Day, 1889, the late Prof. E. E. Barnard of the Yerkes Observatory unintentionally photographed Baily's Beads by replacing the cap on his telescope a second or so too late after taking a final photograph of the solar corona. In recent eclipses the beads have been observed frequently and occasionally photographed. They may be considered one of the most interesting features of very large partial eclipses as well as of total and annular eclipses of the sun. Their appearance preceding total eclipse is a sign that the eclipse will begin within a few seconds while their appearance at the end of totality is a sign that the total phase of the eclipse has passed. When they are seen outside of the path of total eclipse it is a sign that the maximum obscuration is then occurring at the point of observation.

XIII

THE PASSING OF THE MOON'S SHADOW

Immediately preceding the beginning of total eclipse the approach of the moon's shadow may be observed to the westward, if the circumstances are favorable, and, less frequently, its departure eastward at the conclusion of totality. In general, though, the observer's thoughts are so occupied with the corona and other phenomena connected with the total phase of the eclipse that he fails to be on the lookout for the end of totality and when the appearance of Baily's Beads and the first flash of sunlight warns him that the total eclipse is over the shadow is far away to the eastward. The chances of seeing it before totality are better as one is apt to be looking for it then.

There is, however, little chance of seeing the approaching shadow unless one is stationed at a high elevation above the surrounding country with a commanding view toward the west, and in a like manner to observe its departure one must have a clear view of the eastern landscape. During the few brief moments that elapse from the first contact of the observer with the advancing edge of the cone of shadow to his last contact with the following edge all of the phenomena of total eclipse will take place and then the shadow will speed onward and the total eclipse is over in that portion of the shadow belt. The passage of the shadow from Buffalo, N. Y., to New Haven, Conn., at the time of the total solar eclipse of January 24, 1925, a distance of over 325 miles, will be accomplished in six minutes and the entire path of the shadow across the

earth's surface from near Red Lake, Minn., to a point near the Shetland Islands will be passed over by the shadow-cone in one hour and forty-three minutes.

As the shadow travels at an average rate of half a mile a second it will sweep over the observer like some mighty wall of darkness engulfing him with unimaginable swiftness. Compared with the velocities to which we are accustomed the speed with which the moon and its shadow sweep through space is terrific, though compared with other celestial bodies the moon is moving at a rather sluggish rate in its orbit. It is because we have no experience with celestial velocities relative to the earth close at hand except in the flight of meteors and the passing of the moon's shadow that we are so impressed with this phenomenon. At time of eclipse when the shadow of the moon sweeps over us we are brought into direct contact with a tangible presence from space beyond and we feel the immensity of forces over which we have no control. The effect is awe-inspiring in the extreme. In fact, the passing of the moon's shadow, if one is fortunate to observe it, will be one of the most impressive features of the eclipse.

Those who have seen the shadow of the moon approaching or receding do not in general describe it as black but rather as blue-black, violet, or brown, or as resembling smoke or a wall of fog. To some it has appeared "visible in the air" or "gliding swiftly up over the heavens"—to others "like a dark storm on the horizon." So great is its motion over the earth's surface that one has practically no chance to observe it with any success except at high altitudes. Most observers refer to its velocity as "frightful" or "terrifying." Prof. Langley, who observed the approach of the shadow from Pike's Peak at the eclipse of July 29, 1878, was impressed with its distinct appearance. At this high altitude the

shadow would be expected to appear remarkably clear-cut in its outline and in fact another observer likened it to "a rounded ball of darkness with an orange-yellow border" sweeping over the plains beneath him.

By far the best point of vantage for viewing the passage of the moon's shadow is in an aeroplane well above the surface of the earth and at recent eclipses the shadow has been thus observed and even photographhd with some degree of success. Renewed efforts to photograph the shadow will doubtless be made at the coming eclipse of January 24, 1925. The aviator has an unrivaled opportunity to obtain an extensive view of the shadow track in his immediate vicinity, both westward and eastward, and so can catch both the first appearance at the western horizon preceding totality and the last appearance of the fleeting shadow after totality is over.

In a few instances observers have seen the shadow for several seconds preceding or following totality but in general it appears with startling suddenness bringing with it the outflashing glory of the corona and all the attendant phenomena of the total phase of the eclipse.

XIV

THE CHROMOSPHERE AND THE FLASH SPECTRUM

Directly above the visible surface or "photosphere" of the sun, as it is called, there exists a comparatively shallow layer of incandescent gases several thousand miles in depth, known as the chromosphere. At some total eclipses when the moon is so distant that it barely covers the photosphere and leaves the solar atmosphere exposed, the chromosphere may be seen as a narrow ring of a deep rose color contrasting beautifully with the black body of the moon and the pearly radiance of the corona. Generally, however, the moon covers the chromosphere as well as the photosphere and only the scarlet flames of the solar prominences, of which we will speak later, may be seen rising from the hidden chromosphere.

The beautiful rosy tinge of the chromosphere is due to the presence of incandescent hydrogen gas which with helium and calcium may be regarded as the permanent gases that are always present in the chromosphere, and that appear at high as well as at low altitudes.

In the lower, denser layers of the chromosphere, on the other hand, will be found the incandescent vapors of most of the chemical elements that are found on our own planet, including iron, sodium, magnesium, barium, etc. They are often spoken of as the metallic vapors and they are the same elements that are found in the sun itself. This lower layer of the chromosphere is known as the "reversing layer," for a reason that will soon be evident, and in it originates the "flash

spectrum'' first observed by Prof. C. A. Young of Princeton, who discovered it at the Spanish eclipse of 1870.

If the light of the sun is broken up into spectrum colors by means of a diffraction grating, which consists of a number of lines ruled extremely close together, or by means of a glass prism or train of prisms, that is the essential part of the spectroscope, one will observe a number of fine, dark lines on a continuous background of variegated color running from the red to the violet. These dark lines are the Frauenhofer lines or the absorption lines of the solar spectrum. They have their origin in the cooler gases that lie above the photosphere in the reversing layer and they appear dark only by contrast with the more brilliant and hotter background against which they appear.

Now as the moon advances over the photosphere there will come a time, simultaneous with the disappearance of Baily's Beads, when the light from the photosphere is shut off while the chromosphere still remains visible. At this instant if one has a spectroscope pointed at the disappearing sun it will be noticed that the luminous background of the solar spectrum suddenly disappears leaving only darkness while at the same instant the formerly dark lines of the solar spectrum suddenly flash forth as a magnificent series of thousands of brilliant lines. As this phenomenon represents a reversing of the solar spectrum, the luminous background of color becoming dark and the dark Frauenhofer lines becoming bright, the layer of the chromosphere that produces these lines is referred to as the ''reversing layer.'' As its depth is scarcely five hundred miles the moon covers it in a single second. So the flash spectrum is as its name suggests a mere flash of bright lines, gone almost as soon as it is seen.

The appearance of the flash spectrum is an indication of

the beginning of total eclipse and its reappearance immediately preceding the uncovering of the photosphere by the moon is a sign that the end of totality is at hand.

Observations of the flash spectrum are of great scientific value and are always included in the program of observations of eclipse expeditions. They give the astronomer a clue as to the condition of this lower solar atmosphere, the nature of the elements of which it consists and its dependence upon other solar phenomena. The sun is to us the very source of life itself. So every bit of information that may be added to our store of knowledge concerning it is specially to be desired, particularly as there is still so much that is unexplained regarding the great cyclic changes in solar activity that are continually taking place.

The flash spectrum cannot be observed without the aid of a spectroscope or some device for producing the solar spectrum. If one can procure a plane diffraction grating, however, it is possible to observe the flash spectrum with no additional equipment except a pair of binoculars. This method of observing the flash spectrum and recording the beginning of total eclipse was devised by Dr. L. E. Jewell, formerly of the U. S. Naval Observatory, now with the Research Department of the Eastman Kodak Co. and was used first in Sumatra at the total solar eclipse of May 18, 1901. By placing a dark glass before one barrel of the binocular and a small plane grating before the other it is possible to observe the disappearing crescent with one eye and to record the appearance of the flash spectrum with the other. The flash spectrum was observed beautifully in this way at Sawah Loento, Sumatra, by one of the three eclipse parties of the U. S. Naval Observatory through thin clouds at the conclusion of totality. At the be-

ginning of totality the clouds were so dense that no observations were possible.

If the reader has an ambition to photograph the flash spectrum with a modest equipment he will find an interesting description of how this can be accomplished in an article on the coming eclipse of January 24, 1925, in Popular Astronomy for May, 1924, by E. A. Fath; also in the same number a method of photographing the corona with spectacle lenses by Mr. J. H. Worthington. With the kind of instrument described for photographing the flash, Dr. H. C. Wilson, editor of Popular Astronomy, obtained a photograph of the flash spectrum in Colorado at the total solar eclipse of June 8, 1918, upon which 1008 lines could be measured.

XV

THE SOLAR PROMINENCES

A BEAUTIFUL feature of most total solar eclipses are the scarlet flames of incandescent hydrogen, mingled with helium and calcium, that rise to heights of thousands of miles above the surface of the sun at many points and that are now known by the name of solar prominences.

Earlier observers of solar eclipses referred generally to the prominences as the "red flames." The first recorded instance of observation of this phenomenon was by a Captain Stannyan, who saw them at the total eclipse of 1706 at Berne, Switzerland. Writing a description of his observations of the eclipse to the astronomer Flamsteed, he says, in reference to this phenomenon, "— his (the sun's) getting out of his eclipse was preceded by a blood-red streak of light from its left limb, which continued not longer than six or seven seconds of time."

At the famous eclipse of May 3, 1715, which was the last total solar eclipse visible in London, the astronomer Halley observed "dusky but strong red light which seemed to color the dark edge of the moon." From that time on in records of eclipse observations there are a number of references to the "red flames" that appeared during totality.

It now seems strange, when the prominences are a common phenomenon observable by means of the spectroscope in broad daylight as well as during total solar eclipse, that not until the year 1860 was it definitely proven that the "protuberances," as they were then generally called, were associated

with the sun instead of the moon. It appeared to be a common idea up to that time that they were a part either of the atmosphere or surface of the moon. During the eclipse of 1860 visible in the United States and Spain, the observations proved beyond the shadow of a doubt that the protuberances were a solar phenomenon. As the moon advanced over the disk of the sun it was noted that it gradually covered and uncovered the "proturberances," a name which after that was used less and less until it was finally superseded by the more suitable one of "solar prominences." The application of the spectroscope to the study of celestial phenomena about that time, which ushered in the present wonderful age of the "new astronomy," soon revealed the fact that the scarlet color of the solar prominences is due to the presence of vapors of incandescent hydrogen, though lines of calcium were also found to be present in the spectrum of the prominences and a strong, yellow line at first thought to be due to sodium but soon found to be due to the presence of a new element, helium.

A wonderful forward step in the study of the solar prominences was made immediately following the total solar eclipse of August 18, 1868, which was observed in India and the Malay Peninsula for over five and a half minutes, the longest eclipse of which scientific observations had been made up to that time. Here were eclipse expeditions from England, France, Spain and Germany. So great was the brilliancy of the prominences at that eclipse that the French astronomer Janssen, who observed them with the greatest success at Gunteer, during the eclipse, decided to attempt to observe them in broad daylight after the eclipse. This he accomplished by using a spectroscope of wide dispersion which weakened the continuous spectrum background produced by the reflection of sunlight by particles in the earth's atmosphere

while it left unaffected in intensity the monochromatic light of the scarlet prominences.

In the meantime Lockyer, the English astronomer, was working on the same problem and attained success at practically the same time. Janssen had continued his observations of the prominences for some days following the eclipse but delayed in communicating his results to the French Academy of Sciences so at the meeting that fall two papers were read on observing the solar prominences in daylight, one by Lockyer and the other by Janssen, and a gold medal was struck by the French government in honor of the brilliant discovery made independently by the two astronomers.

Many attempts have been made also to photograph the solar corona in broad daylight but owing to the extreme faintness of its light all attempts have so far been in vain.

At total eclipses that occur during the sunspot maximum period the solar prominences are almost invariably extremely beautiful and intricate in form and conspicuously visible even to the naked eye. Sometimes they are found associated with sunspots and sometimes they occur entirely independent of them but there appears to be some close connection between the coronal streamers and the solar prominences. "Hooded" or "arched" prominences, for example, are frequently observed during the sunspot maximum periods in which coronal streamers seem to form a hood or arch over the prominences. Also long coronal streams seem at times to have their origin in the vicinity of conspicuous prominences. The connection between the coronal streamers and the prominences is one of the most interesting of the problems that the scientific observer of solar phenomena has to solve. It is believed that streams of electrons affecting the earth's magnetism and causing auroral displays may be shot off from the sun in the vicinity of

Disturbance on south-west limb of sun. The arches are immediately over a large sunspot. Note large solar prominence to right of arches. Photograph taken by Sproul Observatory Expedition, Mexico, September 10, 1923.

prominences as well as from sunspot regions. There are many solar problems still awaiting solution that may have a very direct bearing on magnetic and electric phenomena of the earth's atmosphere, including wireless and telegraphic communication. It is never known when some apparently abstract piece of information gleaned from scientific observations at times of total eclipses of the sun may have a very important association with terrestrial affairs. It may be well to recall here that the yellow line in the spectrum of helium was first observed in solar prominences before it was seen on earth; that in the year 1868 Lockyer gave this name of "helium" to the hypothetical element that he observed in the spectrum of the sun.

Not until twenty-seven years later did Ramsey find the same line in the spectrum of an inert gas obtained from the mineral clevite. Lockyer's helium discovered in the solar spectrum in 1868 and the new gas found on the earth by Ramsay in 1895 were the same.

Prominences are of two classes, eruptive and quiescent. The quiescent prominences may persist practically in the same form for days at a time, floating above and often apparently detached from the solar surface, like terrestrial clouds. The eruptive prominences assume strange and rapidly changing forms. The entire aspect of an eruptive solar prominence may be entirely changed in a brief fifteen or twenty minutes. The height attained by prominences of both varieties is sometimes enormous. Though exceptional,—altitudes of 200,000 to 500,000 miles have been recorded. A record breaking prominence of a few years ago attained an altitude of over 500,000 miles, or more than half of the diameter of the sun. In general though the prominences do not exceed 20,000 miles in height, particularly during sunspot minimum periods.

The total solar eclipse of June 8, 1918, occurred during a sunspot maximum period and the prominences that were so conspicuously visible during totality were particularly beautiful and interesting in form. The photographs also indicated that the prominences were affected by strong currents in the solar atmosphere blowing toward the solar equator. Two striking prominences seen at this eclipse were the Heliosaurus prominence, so named from its resemblance to the skeleton of some prehistoric animal, and the Eagle prominence, which resembled an eagle alighting on a lofty mountain. They remind one of the strange forms that are seen in fancy in summer clouds. Yet compared to the "skeleton" prominence, estimated to be at least 40,000 miles in height, our whole earth with its diameter of 8,000 miles would be a rather insignificant object.

In sharp contrast to the 1918 eclipse with its strikingly beautiful prominences is the eclipse of September 21, 1922, observed in Australia, at the sunspot minimum period. Observers found that at this eclipse not a single prominence was visible to the naked eye.

As the sunspot minimum period is now well past and solar activity is setting in once more it is probable that prominences will again be visible at the eclipse of January 24, 1925, though not as conspicuously as at the 1918 eclipse.

Past observations of eclipses show that in some instances the prominences have been visible for as long as five or six minutes before and after the total phase of the eclipse though in general they are seen only during totality.

"Heliosaurus" and other prominences photographed by Yerkes Observatory Eclipse Expedition at Matheson, Colorado, June 8, 1918.

XVI

THE SOLAR CORONA

THE glory of a total solar eclipse lies in its corona. It is the phenomenon that is of the greatest interest to the spectator and of the greatest scientific value to the astronomer, who seeks to solve its mystery.

The corona appears only when the light of the sun is completely blotted out, simultaneously with the appearance of the flash spectrum at the beginning of total eclipse, and it disappears with appearance of Baily's Beads at the end of totality. So faint is its light, scarcely exceeding that of the full moon at best, and usually considerably less, that all of the numerous attempts that have been made to observe it without a total eclipse have so far failed.

In the clear, rare air of Pike's Peak during the total solar eclipse of 1878, Prof. Simon Newcomb and Prof. Langley independently traced the delicate coronal streamers to the tremendous distance of twelve solar diameters or about eleven million miles from the sun, and held them steadily in view for more than four minutes after the end of totality, but this was exceptional. It is probable that in airplanes at high elevations above the earth's surface much more detail would be seen with the naked eye than at sea level but as the shortest exposures used in photographing the corona are a second or over while exposures of thirty seconds or more with powerful cameras are common, there is little, if any, chance of attaining success in photographing any detailed structure in the corona from airplanes. Amateurs who wish to attempt

to photograph the corona might attain some success with small cameras with an exposure of about five seconds or by using a camera attachment with a small telescope on an equatorial mounting.

The wealth of delicate tracery and detail in the structure of the corona that the long exposure photographic plates reveal cannot be appreciated from looking at the photographs for much of this detail is lost in the printing and more in the reproductions. Neither can one appreciate the exquisite pearly radiance of the coronal light as it appears to the observer in striking contrast to the vivid scarlet of the prominences and the forbidding darkness of the moon.

The details of structure in the form of the corona are never the same in any two eclipses though there is a general change in type with the eleven-year sunspot cycle that is so marked that the astronomer can predict in advance the form of corona if he knows at what part of the sunspot cycle it will occur.

At and near the time of maximum spottedness of the sun, when the solar activity is greatest, when the sun is hardly ever free from spots and when solar prominences are most conspicuous the solar corona is evenly developed all around the solar surface and is more than normally bright. At the sunspot minimum period, when the sun is often free from spots for days at a time and when the prominences are few and inconspicuous and generally confined to the sunspot zones within a belt forty degrees wide on either side of the solar equator, then there appear short, bushy coronal streamers separating sharply to eastward and westward above the solar poles, like the lines of force emanating from the ends of a bar magnet, while in equatorial regions of the sun long coronal streamers extend to distances of several solar diameters or several million miles from the sun. The corona is then

much fainter in general, than at sunspot maximum and few if any conspicuous prominences are visible to the naked eye. At times intermediate between sunspot maximum and minimum the corona is intermediate in type, being roughly rectangular in shape. The United States eclipse of June 8, 1918, which occurred during a sunspot maximum period, was noted for the number and beauty of its prominences and for the brightness and intricacy in structure of its corona, which, true to type, was evenly developed around the solar disk, the short bushy polar streamers being concealed by the longer superimposed streamers.

The eclipse observed in Australia September 21, 1922, occurred, on the other hand, very near the time of sunspot minimum and the corona was very inferior in brightness to the 1918 eclipse: no prominences were visible to the naked eye while those revealed telescopically were small and few in number. This eclipse also was true to type with the short bushy polar streamers parting sharply over the solar axis of rotation, which coincides closely with the sun's magnetic axis. The long equatorial streamers were also clearly in evidence. The relative smallness and faintness of the corona showed that the sun was in a remarkably quiescent state. The eclipse of September 10, 1923, observed in Mexico by the Sproul expdition of Swarthmore College and by the Mexican National Observatory expedition was brighter and showed signs of a gradually awakening solar activity. Prominences were plainly visible in small telescopes but not to the naked eye and were not of their usual vivid scarlet, being described as whitish in appearance. The polar streamers at both poles were very long and well-defined but faint, the north-polar streamers being traced to a distance of over half the diameter of the sun, or something like five hundred thousand miles from

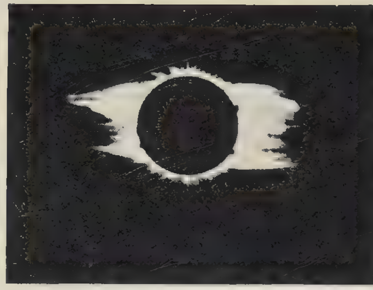
the sun. They were longer but less bright than those around the southern pole. The corona on the eastern side of the sun was very simple in structure although three large prominences of the quiescent variety were visible on that side. The corona on the southwestern side was not nearly as simple, however, being even more complex in that particular region than the corona of 1918.

It may be predicted that the corona of the coming eclipse of January, 1925, will be brighter and more evenly developed than the last eclipse and prominences may be expected to in evidence,—though this is to some extent a matter of cha As the period is intermediate between the sunspot maxim and minimum the corona should be of the rectangular or intermediate type. As the sunspot minimum was passed in the spring of 1923, or possibly earlier, the maximum should not occur until 1928, but the rise to maximum spottedness is much more rapid than the decline to minimum. There are now signs that the new cycle of solar activity is well started.

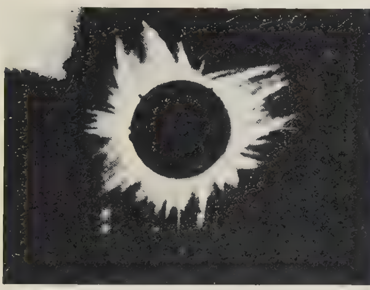
It has often been observed that the coronal streamers have a tendency to form conspicuous arches or "hoods" over eruptive prominences. The seat of coronal disturbances, in fact, often seems to lie in the vicinity of the prominences, and there seems to be a close connection between the prominences and the corona. Yet the lines of hydrogen and calcium gas that are conspicuously present in the prominences are never found in the spectrum of the corona. There appears to be, in general, no noticeable connection between groups of sunspots and coronal streamers, such as exists between prominences and corona.

The origin and the nature of the solar corona and the reason for its change of form with the sunspot cycle are still unknown but it is believed the astronomer is much nearer the solution

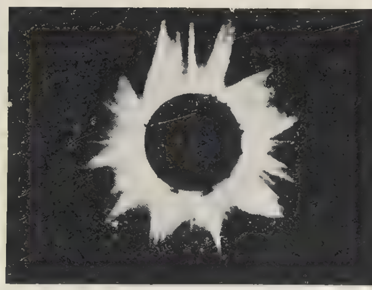
July 29, 1878
(Peers)



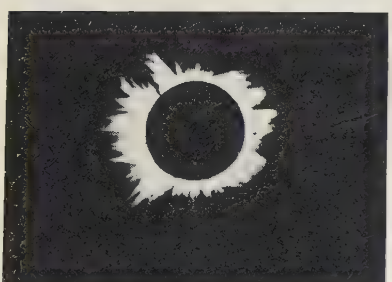
January 1, 1889
(Barnard)



May 6, 1883
(Abney)



April 16, 1893
(Schaeberle)



August 29, 1886
(Schuster)

August 9, 1896
(Kostiosky)

Six views of Corona showing change of type with the sunspot cycle.

of these problems than he was a few years ago. It is certain, for instance, that the corona consists partly of minute particles of matter that scatter and reflect the light of the sun, particles that are probably driven off from the sun itself by light pressure and in other ways. In addition there is probably a photoelectric effect, that accounts for much of the luminosity of the corona, produced by the passage of streams of electrons through the rare gases of which it consists just as the light of the aurora is a photoelectric effect produced by a bombardment of the rare gases of the earth's upper atmosphere by streams of electrons from the sun. The spectroscope shows that there are a number of bright lines in the spectrum of the corona, which indicates that it shines partly by its own light. A conspicuous bright line in the green has been attributed to an unknown element, coronium, that has been found nowhere except in the corona. There is also an unknown line in the red that is very conspicuous at times and, in addition, a number of other lines of unknown origin.

It is believed that these may be lines, not of unknown elements, but of some familiar elements electrically excited. It is possible that the bright lines of the unknown nebulium in the rare gaseous nebulas are produced in an analogous way and when the source of the coronium rays is found the cause of the presence of nebulium in the nebulas may be explained also. It is probable too that other suns as well as our own have their coronas but that they are masked by the far more brilliant radiations of the stars themselves, just as is the case with our own sun, except during eclipse.

Also, it may be that much of the intricate tracery of the coronal streamers and complex structure that is caught by the photographic plates and the eye of the observer during totality

results from the fact that the sun like the earth is a magnet and is surrounded by a strong megnetic field.

It is still unknown whether or not the corona rotates with the sun though efforts have been made and are still being made to settle this question by observations made at each total eclipse. Also efforts have been made for some time to determine whether rapid changes in coronal form take place, during the time that elapses between the observation of the eclipse at points a considerable distance apart in the shadow path. So far it has either been impossible to obtain photographs for comparison at the widely separated stations or else only negative results have been obtained. No light can be shed on this problem in the coming eclipse of 1925 as all available stations are only a few minutes apart in time.

It is probable that when the radiations of the corona are understood the whole problem of solar radiation and the cause of the sunspot cycle will be understood. So the problem of the cause and nature of the coronal radiations and the reason for the change in form of the corona with the sunspot cycle are the greatest of eclipse problems. So far no way to approach their solution has been found except through observation of total eclipses of the sun. Partial solar eclipses are of course useless for this purpose as well as the annular type of eclipse. As the problem of solar radiation is so vitally associated with electric and magnetic changes on the earth as well as meteorological changes its solution is one of great practical value. Radio and telegraphic communications, temperature and rainfall on earth may all be affected by the same change in solar activity that produces a sunspot, an eruptive prominence, a stream of electrons or a change of structure in the corona. It is the cause of important solar changes and their effects that the astronomer seeks to discover

through the observation of the corona during a total solar eclipse. The time granted for the solution of this problem is pitifully small, possibly two minutes this year or three or four minutes, or none, next year.

From the time when photography was first applied to the observation of the solar corona, in 1860, up to the present day the total time available for the study of the corona has probably totaled less than a single hour, so it is not to be wondered at that our knowledge of the nature of the coronal radiations has progressed slowly. There has been accumulated by this time, however, a fine series of coronal photographs secured at practically all phases of the sunspot cycle and it is only a matter of a few years at the most before these scientific records of eclipses, secured in some instances by expeditions sent to strange and far-away corners of the earth, should begin to bear fruit. It is possible that valuable and far-reaching discoveries regarding the nature of solar energy may be forthcoming in the near future as a result of the scientific observations of total solar eclipses, though this progress is necessarily so discouragingly slow. Prof. W. W. Campbell, Director of the Lick Observatory, who has probably observed more total solar eclipses than any other man living today, has estimated that all the time that he has been granted for observations of the corona and other phenomena of totality has totaled less than one half hour! The astronomer who stays at home is fortunate if he sees one solar corona in a life time.

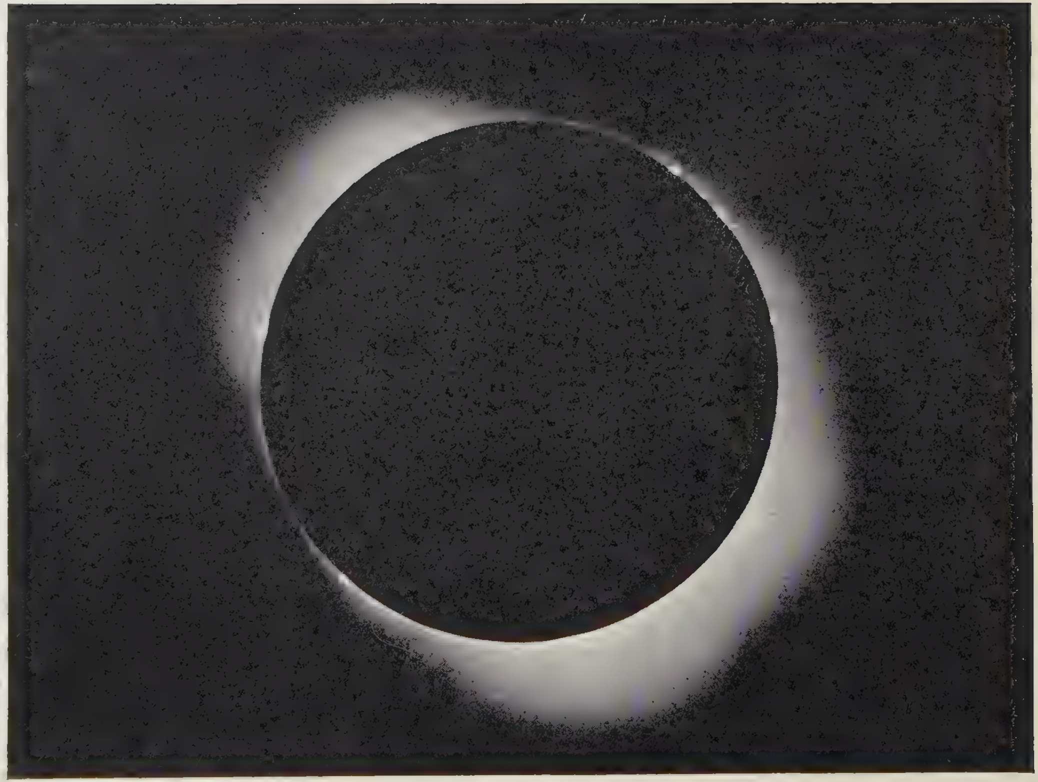
XVII

THE ECLIPSE PAINTING

The first, and so far the only painting of a total eclipse of the sun, was made of the eclipse of June 8, 1918, by Mr. Howard Russell Butler, the well-known portrait painter, who with this object in view became a member of the U. S. Naval Observatory expedition to Baker, Oregon.

The idea of an eclipse painting was conceived by Mr. Edward D. Adams, of New York, founder of the Ernest Kempton Adams fellowship awarded each year by Columbia University for researches in the field of pure science. It was Mr. Adams' desire to secure, by means of photography, drawing or painting, a reproduction of an eclipse that would be true both as to color and form.

Unfortunately not only are the exquisitely contrasting color effects of pearly corona, dusky moon and rose-tinted prominences lacking in the photographs, but much of coronal detail is lost in the reproduction because of the great difference in brightness between the inner and outer corona. An exposure long enough to bring out the faint outlying coronal extensions is too long for the far more brilliant inner corona which appears as a glare of light lacking in deatil as a result of overexposure. The only successful method of reproducing coronal detail has been by means of composite drawings from a number of negatives taken with different exposures and different cameras. By this means all the detail in both the inner and the outer corona can be reproduced. Yet these drawings do



The Corona of June 8, 1918. Photograph taken by U. S. Naval Observatory Expedition, at Baker, Oregon, with camera of 65-feet focal length.

not reproduce the superb color effects of the eclipse and so Mr. Adams undertook to find the man who could both draw and paint the corona and prominences. That he was highly successful in his search all will agree who have had the opportunity to see the painting of the total solar eclipse of June 8, 1818.

Three paintings of the eclipse were made by Mr. Butler, the first immediately after the eclipse, the second on the following day and the third after all data had been secured. One of these paintings was presented to the American Museum of Natural History in New York by Mr. Edward D. Adams, and may be seen in the Astronomical Room, which is kept darkened except for the indirect lighting of the painting of the eclipse.

A description of the methods used in painting the eclipse and the manner in which it was observed by him is given by Mr. Butler in Natural History, 19, 244-271, 1919, published by the American Museum of Natural History.

The usual time that he asks for in painting a portrait, Mr. Butler states, is ten or twelve sittings of two hours each. In the painting of the eclipse he found that he was required to render his subject in 112 seconds! It was, moreover, the first total solar eclipse that he had ever seen.

All those who have seen both the painting of the corona by Mr. Butler and the original agree that the reproduction is wonderfully accurate both in color and in form. Happily too the eclipse of 1918, which occurred at the sunspot maximum period, was remarkably rich in coloring, the prominences, in particular, being unusually brilliant and conspicuous in size and shape. Several of the more noticeable prominences were, in addition, "hooded" or arched over with series of coronal streamers producing a most beautiful and curious effect.

It was peculiarly fitting that this most resplendent of recent eclipses should have been the one chosen for reproduction in colors. So skillfully is Mr. Butler's painting of the eclipse executed that it deserves to be classed high among the contributions to science that are a product of eclipse expeditions.

XVIII

HOW TO VIEW THE ECLIPSE

NOTHING is essential for observing a total eclipse of the sun successfully except a good pair of eyes, though a pair of binoculars or opera glasses might be used to advantage in observing the solar prominences and the corona during the total phase of the eclipse. These should be adjusted and focussed in advance, however, for the moments of totality are short and precious and if you cannot make use of the glasses quickly and easily it would be wiser to dispense with them altogether. In no case should binoculars be used during the partial phase of the eclipse without taking the precaution to fasten a piece of dark or colored glass over the ends to protect the eyes.

The flash spectrum cannot be seen unless one has some means of forming the solar spectrum as explained in Chapter XIV but aside from this the general observer has just as good a chance of seeing all the principal features of the eclipse as the scientific observer,—in fact, a better chance, for the astronomer who is engaged in making scientific observations during the total phase of the eclipse or in photographing the corona must give his undivided attention to his instrument and can at most spare only a hurried glance for the scenic splendors of the eclipse.

Though the amateur has the best of it when it comes to opportunities for observing the various features of the eclipse the chances are that he will observe next to nothing unless he knows in advance what to look for and when to look for it. The wise man will plan to make the most of his opportunities.

It is well not to strain or fatigue the eyes by gazing needlessly at the sun during the partial phase of the eclipse even when the precaution of using dark glasses is taken. It will be an hour or so from the time of "first contact," when the partial phase of the eclipse begins, up to the time when the thin solar crescent breaks up into Baily's Beads and the corona flashes forth in all its ethereal splendor. During the earlier part of this period there is nothing of scientific interest and little of general interest to observe, aside from the recording of the time of first contact of the rims of sun and moon and the recognition of the fact that the eclipse is "on."

When the magnitude of the eclipse has become as great as eighty percent or so the visible part of the sun will have become decidedly crescent shaped and the light will have diminished to such an extent that the landscape will begin to take on a strange aspect, as if viewed through yellow glasses. Look now for crescent shaped images of the sun formed by passing its light through very small openings or through lenses. When the leaves are on the trees the small openings between the leaves act as tiny lenses casting small images of the eclipse on the ground,—numberless little crescents with their horns turned in a direction opposite to that of the crescent sun above. This interesting phenomenon produced by the leaves cannot of course be observed in a winter eclipse and we must look elsewhere for our crescent shaped images of the sun or find a means of producing them for ourselves.

By this time it may be noticed that birds and animals are displaying a strange uneasiness and in the past this uneasiness was by no means confined to animals alone. One of the greatest services of astronomers to mankind has been to free the more civilized nations of the world from the terror and panic that always attended the appearance of such phenonena

as eclipses and comets. Even at the present time this fear of eclipses is very general among the ignorant classes in China and in India and among uncivilized races in many lands. The ringing of gongs and the beating of drums is still common in Asia during lunar as well as solar eclipses, where the belief that a dragon with dark claws is attempting to devour the sun or moon still persists.

When the solar crescent narrows to a thin line look for the shadow bands. They often appear as early as five minutes before the total eclipse begins. All observers who are within the path of total eclipse are urged to make observations of shadow bands as outlined in Chapter XI. Here is a chance for everyone to do his little bit for science and if one can succeed in photographing this phenomenon he will accomplish a feat that no one has succeeded in accomplishing up to the present time, though many attempts have been made at past eclipses. Also, do not forget to look for the shadow bands directly after as well as before the total eclipse.

About this time or even earlier look for the appearance of the brighter planets. Venus, Mercury and Jupiter appear in a close group some distance to the southwest of the sun during the total eclipse of January 24, 1925. Venus will appear before any of the other planets or stars because it is by far the brightest, next Jupiter will be seen, then Mercury close to Venus and, to the northwest of the sun, the first magnitude star, Altair, and still more distant in the same general direction Vega, one of the brightest stars in the heavens.

Within the last few minutes preceding the beginning of total eclipse there is plenty to occupy the attention of the observer. The landscape has now taken on a strange hue. The appearance of the shadow bands adds to the unearthly

effect. The solar crescent is now narrowing to a mere line. Be on the watch for the appearance of Baily's Beads. It is said that at some eclipses they are not observed. At the same time be on the lookout for the approach of the shadow from the west if you are at some elevation above the surrounding country and in a favorable position to observe its approach. It will appear as Baily's Beads disappear and a second later you will be gazing upon the unrivalled beauty of the solar corona with all of its delicate tracery and intricate detail. Note its color and brightness and general form; also estimate the extent of its equatorial streamers, using the diameter of the sun or moon for comparison. Are there pronounced polar brushes and long equatorial extensions to the corona,—the sunspot minimum type—or are the polar brushes absent and the extension of the corona fairly regular in all directions? Are there prominences visible to the naked eye and what is their color? Are they deep scarlet, rosy hued or whitish? Do the coronal streamers form arches or hoods over the prominences? Make a rapid sketch of the form of the corona and the location of the principal prominences. Take particular pains to do this if no astronomical expeditions are located in your vicinity for there is a chance that you may be favored with fair weather and the astronomers not, in which case your little sketch may be of value. Photographs of the corona may be attempted with ordinary cameras with a time exposure of about five seconds but much detail cannot be expected to appear on these photographs. Note the appearance of the moon. Is it inky black or grayish? Does it stand out in relief as a huge globe? Observe the beautiful contrast in color between the pearly radiance of the corona, the rose-colored prominences and the dusky moon. Note the degree of darkness of the eclipse. Is it possible to read or see the hands

of your watch? It has been found that the degree of darkness varies greatly at different eclipses.

It is a good idea to form a small observing party with a number of friends each agreeing to give particular attention to some one phase of the eclipse, shadow bands, prominences, sketches or photographs of the corona, etc., while observing more generally all phenomena so far as possible. In this way some observations of real scientific value may be obtained while in any case the general observer will be satisfied that he has made the most of a rare opportunity to witness a spectacle such as most of us do not have the privilege of seeing once in a life time.

The following interesting description of the Australian eclipse of September 21, 1922, as it appeared to a layman, is taken from a diary of the event written by S. Elliott Napier and published in the Sydney Mail. The place of observation was the small town of Goondiwindi in New South Wales. We quote it as giving an excellent idea of what any observer of a total solar eclipse may expect to see in general. As regards the failure to see any prominences we would recall that this eclipse occurred at the sunspot minimum period when the sun was in an unusually quiet state and, according to the report of the Lick-Crocker Expedition, which observed the same eclipse at Wallal on the western coast of Australia, no prominences were visible to the naked eye at this eclipse.

THE GREAT DAY

Thursday, September 21, 9 a.m.—Brilliantly fine. Not a cloud. SW wind. Cold night. Town crowded at an early hour—10 a. m. Governor (Sir Matthew Nathan), who arrived at midnight, given civic reception. The eclipse is now under vice-regal patronage, and the last chance of a failure is there-

by removed. The scientists' camps bustling like disturbed ant-heaps—each lot getting its last details overlooked and its last button polished. I am to have a corner in the sacred preserve and a star-chart, and my job is to locate the stars and planets that become visible and the respective times of their appearance as closely as possible. A sheet to "catch" the shadow bands has been laid on the ground near the fence, and two cameras trained on it. These are to be worked by Mr. Edwin Fletcher (solicitor, of Goondiwindi, to whose kindness the visitors in the town generally, including myself in particular, are deeply indebted), and his daughter. They are instructed in their duties by Mr. Booth, the spectroscope king, who is a genial person with a habit of saying "Quite—quite!" when he means to emphasize his affirmations. Under the excitement of the occasion I hear him firing a feu-de-joie of "Quites" that would do credit to Mark Twain's echo. All who can are asked to watch for and note as particularly as possible the direction in which the shadow bands move, their approximate thickness, the distance between them, their rate of speed, and when they commence and how long they last.

2 p.m.—People everywhere: many of them already looking at the sun through glasses—especially in the bars; the town very lively with cars—I count 47 in the main street as I go to "stations." The clouds have all disappeared. Wind very fresh from SW causes the coelostats which serve the various telescopes to tremble.

2.30p. m.—Everybody reported for duty; all watches synchronized; everybody ready—even Father Pigot has a moment to sit down and murmur soothing words to his beloved pyranometer. I understand that during a slight altercation in its vicinity between two of the scientists this morning it recorded a heat rediation that nearly wrecked the galvanometer. My

notes from now on must necessarily be brief—the hour approaches. A special theodolite telescope has been set up for the Governor, who is to arrive shortly—and by an arrangement of tinted glasses it shows the sun as a disc of blue. The "blue moon" is familiar; but this is the first sun of that shade I have met with. A slight smoke from the railway pumping plant hazes the sky a bit towards the west.

3 p.m.—A little less than 6 minutes to go before "first contact." Conditions perfect.

3:5.58.—Mr. Nangle, looking through the V. R. theodolite, announces "first contact"; in a few seconds everybody notes it.

3:6.50.—Cusp showing up distinctly in all telescopes. The eclipse is "up to time."

3.18—Great excitement! The Governor, applying for admission at the back gate, has been thrust with ignominy away. Will we all be arrested for lese majeste?

3.25.—All well again. The Governor is a sport, and—went round to the front and was admitted. He goes to his little telescope, and everybody is happy. About a quarter of the sun is now obscured. I try to see the "pictures of the eclipse" thrown on the ground by the light filtering through the leaves. Unsuccessful—probably, the trees being peppers, the foliage is unsuitable.

3.47.—Cocks crowing and birds flying about in some alarm; distinct failure of light and fall in temperature; about half sun.

3.52.—Venus visible (probably earlier than this—but this is the first moment I saw her.) Peculiar deep blue tint assumed by western sky. The shadows of all objects are taking on fantastic edgings and distortions.

4:8.—Sun now a mere crescent; fall in temperature; slight breeze springs up; three minutes to go before totality.

4:9.—Jupiter visible; the light grows more and more weird. There is little talk, except in whispers.

4:10.—Mercury visible; Saturn visible; and, looking back towards east, I see Mars quite plainly. He has evidently been visible for some time. The breeze has died down to a complete calm. One minute to go. "Shadow bands" clearly visible about half a minute later.

4:11.40.—A sudden flash, and the sun disappears. Time-keeper calls "Go!" The black silhouette of the moon is suspended against the corona. Latter of a beautiful silvery glow. I see no colors, neither do I observe any "prominences" or "Baily's Beads." I draw a rough sketch of the corona (which agrees fairly well on subsequent comparison with those of other observers, showing four extensions—two above, two below—the left-hand lower one being the largest of the four, and the right-hand lower one having a serrated terminal edge). Black prominence on moon. Not so dark as I expected, but light unlike anything I ever saw—neither moonlight nor twilight—more like "seeing through a glass darkly" than anything else. I notice Spica between Mercury and Jupiter; also B. Leonis and—I think—B. Virginis, quite close to the sun; one of the "Einstein" stars; a glance round to the south shows three of the stars of the Cross, also both pointers. Finally, I note Arcturus to the north. The most notable features of totality: the eerie appearance of the dead-black moon against the radiant corona—a veritable "study in black and silver"—the incomparable beauty of the corona itself—its sudden appearance, and the "flash" which heralds the beginning and end of totality. Also the extraordinary weirdness of the light. I notice a golden—almost reddish—glow

round the horizon (probably the reflected light from the unshadowed portion of the earth, 75 miles away). Very little said by anyone; but of the awesome and wonderful impression made there can be no doubt.

4:15.20.—A sudden dazzling flash and totality ends. The lower limb of the sun is uncovered, and the "shadow bands" reappear. We all try to gauge their size, distance apart, direction, etc., but it is a hard thing to do; much variety of opinion; the majority seem to favor a direction E of north, and to think that they are about six inches apart. (I should have thought nine or ten.) They are gray wraiths of shadow —something like smoke, or the shadows that ripples make in a pool. They move faster than I expected. I hear the cameras click, but I think the light is too faint and the bands too fast for any successful result. All the stars disappear at once but Venus, Jupiter, Mars, Mercury, and Saturn are still visible. The corona is gone like a flash. The rest is an anti-climax.

4:20.—Everybody seems satisfied that good results have been obtained. Father Pigot still keeps his pyranometer going—also Professor Vonwiller and Mr. Briggs and Mr. Aston in their shed for a while with their "intensity" records.

4:50.—Everybody adjourns to the other observing stations to exchange views.

5:14.55.—Last contact. Poor old sun! Nobody pays any attention to him now. *Sic transit gloria solis.*

5:20.—Everybody photographed, everybody happy, everybody tired. Finis. (I am told that certain flowers called, locally, "bluebells," closed during totality. The cocks crew quite a bit when the light returned, and the fowls, looking very foolish, came off their perches. Also many birds left their roosts in the trees.)

XIX

HOW THE ASTRONOMER OBSERVES AN ECLIPSE

Long before the track of a total solar eclipse is due to pass over the earth's surface the astronomer is considering the advisability of placing himself and his instruments within it for the purpose of making certain important observations that can be made only when the sun is totally obscured.

If the eclipse path touches land under favorable circumstances, that is, with the sun at a considerable elevation above the horizon, with promising weather conditions, and a duration of totality of approximately two minutes or over, the chances are that every effort will be made to have at least one eclipse expedition in the field. Frequently astronomers from a number of the leading countries of the world occupy stations at different points within the shadow track. When the total phase is exceptionally long, say from four to six minutes, special efforts are made to observe it even if it is necessary to travel half way round the world to do so.

Expeditions have been sent to strange and out of the way corners of the globe to observe total eclipses of the sun. A coral island in mid-Pacific, the banks of the Saskatchewan, the island of Sumatra, the coasts of Siberia, Labrador and Africa have been some of the objectives of eclipse expeditions. Some of these expeditions have attained splendid success, others have met with defeat from clouds but the sum total of knowledge gained from the observation of eclipses has been well worth the trouble and expense incurred in observing them.

The weather has ever been the despotic ruler over the fates of eclipse expeditions. It is customary to get records whenever possible of weather conditions for a period of several years at points favorably located within the shadow path in order to minimize the chances of selecting stations where the weather promises to be unfavorable at the particular time of the year and day when the eclipse will occur.

For the first time in the history of eclipse expeditions, insurance was taken out against failure to obtain observations during the period of totality in the case of the eclipse of September 10, 1923. This was done by the Sproul Observatory Expedition of Swarthmore College, which was stationed at Yerbanis, Mexico. As it happened, this was the only American expedition sent out to observe this eclipse that did not meet with defeat from clouds. Let us hope that more expeditions will be insured in the future if this is to be the result! The prediction of weather conditions, after all, is largely a lottery as can be judged from the fact that the best weather conditions for the time of the year at which this eclipse occurred promised to be in California, and on the western coast of the peninsula of Lower California. Here most of the expeditions located and here, as it happened, dense clouds and fog prevailed during the eclipse hour.

The Mexican National Observatory expeditions, located at Yerbanis and Laguana Seca, Mexico, obtained valuable records of this eclipse at both stations though torrential rains fell on the morning of the eclipse at Yerbanis and at the beginning of totality the sun was visible through thin clouds. These did not affect the photographs, however, and rapidly cleared away, leaving the latter half of the eclipse visible in a perfectly clear sky so that the entire program was carried out successfully by both the Swarthmore and Mexican expeditions.

The chief object of all eclipse expeditions is to obtain photographs of the corona, for the purpose of studying its form, structure, and extent, as well as spectrograms, that is, photographed spectra, of the corona and of the lower solar atmosphere—the reversing layer and the chromosphere—for the purpose of finding out the nature of the unknown elements that exist in the corona and the constitution of both corona and the solar atmosphere.

The equipment of the average eclipse expedition consists essentially of telescopic cameras, of focal length between two and nine feet generally, for photographing the outer extensions of the corona and the region surrounding the sun, also, in addition to these telescopic cameras, several grating or prism spectrographs for obtaining photographs of the flash spectrum and the spectrum of the corona. The equipment may include, in addition, interferometers for determining the rotation of the corona and instruments for measuring the nature and intensity of its light. In recent years a moving picture camera is frequently included in the equipment of eclipse expeditions for the purpose of obtaining photographs of educational value of the eclipse camps and instruments and of all phases of the eclipse from first to last contact.

A large photographic telescope, or camera, of focal length forty to sixty feet, which takes photographs of the eclipse on a large scale is the most unwieldy and cumbersome piece of the eclipse outfit. It is mounted either in the form of a tower pointed directly at the sun or horizontally. In the latter case it is fed by means of a coelostat which reflects the light from the sun and which may at the same time reflect light to other instruments. This large camera usually has a lens of five or six inches aperture and forms an image of the sun five to seven inches in diameter. The sixty-five foot camera used

by the U. S. Naval Observatory expedition to Baker, Oregon, in 1918 gives an image over seven inches in diameter and the six-inch photographic telescope of the Yerkes Observatory used in 1900 and 1918 has a focal length of sixty-one and a half feet and gives a solar image seven inches in diameter. It was planned to use this instrument at the eclipse of September 10, 1923, in a horizontal position, feeding it from a coelostat with an eleven and a half inch flat mirror.

During the total phase of the eclipse, eight or ten photographs can usually be taken with such an instrument, the exposures generally ranging in length from about one second to over sixty seconds. At Fort De Kock, Sumatra, in 1901, Prof. G. H. Peters of the U. S. Naval Observatory Expedition took ten photographs with the forty-foot camera, with exposures ranging from one-half to sixty seconds. The Yerkes Observatory Expedition stationed at Catalina Island in 1923 planned to take six exposures with their sixty-one-foot camera, two exposures of one second each and four of four, eight, sixteen and one hundred and twenty seconds respectively. The Lick-Crocker Expedition to Wallal, Australia, in 1922 took a long series of photographs with their forty-foot camera, with exposures ranging from one-fourth of a second to sixty-four seconds.

The smaller telescopic cameras which are used to photograph the outer corona and field surrounding the sun are usually mounted on a single polar axis driven by clock work or by means of a clepsydra or some other device for counteracting the diurnal motion of the earth. The motion imparted to the axis by this means is opposite in direction and equal in amount to that of the earth on its axis so that the solar

image appears immovable in the field. Often the spectrographs and other instruments are also mounted upon the same polar axis. The Lick-Crocker Expedition to Wallal in 1922 attached to one polar axis a camera of five inches aperture and sixty-six inches focal length and five spectrographs. The Sproul Observatory expedition to Yerbanis, Mexico, mounted on one polar axis, two grating spectrographs, an Etalon interferometer for determining the rotation of the corona, and a motion picture camera. On another polar axis were mounted the "twin Einstein" cameras fifteen feet focal lengths and 6¾ inch apertures with quadruple lenses which covered an 18x18 inch plate.

The expedition to Wallal had a pair of similar Einstein cameras and in addition another Einstein pair of four-inch aperture and five-foot focal length. These cameras are employed primarily for photographing field of stars immediately surrounding the eclipsed sun for the purpose of studying the Einstein effect, which is the displacement of the images of stars near the sun from their normal position and away from the sun as a result of the effect of the sun's gravitational field upon the path of a ray of light passing through it.

It was predicted by Einstein some years ago that this effect would be observable at the time of a total solar eclipse, when the stars near the sun are visible. At the eclipse of May 12, 1919, the British expeditions to Brazil and Africa first obtained evidence that such an effect might exist and results of their observations have been confirmed by observations made with the Einstein cameras at Wallal in 1922 by the Lick-Crocker Expedition. So perfect is the agreement between the observed deflections recorded by these four cameras and the predicted "Einstein effect" based upon the principles

ove: The camp of Sproul Observatory Expedition at Yerbanis, Mex-
. Total Solar Eclipse September 10, 1923. Showing the sixty foot
nera, in front of which are the Einstein cameras and a polar axis
veying a number of smaller instruments.

ow: Camp of Lick Crocker Eclipse Expedition, Wallal, Australia. Total
ar Eclipse September 21, 1922. Showing the Polar Axis, carrying
ectrographs, five-inch Telescope, and two Short-Focus Cameras. The
th side of the shelter for the Einstein Cameras is visible at the right.

of the Einstein Theory of Relativity that Prof. W. W. Campbell, director of the Lick-Crocker Expedition, considers that so far as the Lick Observatory expeditions are concerned, the problem has been settled in favor of the Einstein effect and will not be taken up by future expeditions sent out by that observatory. The results obtained by the Sproul Observatory Expedition which undertook a solution of the same problem during the eclipse of Sept. 10, 1923, have not been reduced yet and are awaited with great interest as this is considered to be one of the most important physical problems of the present age.

Two, three or even five minutes seem a ridiculously short period to be allotted at intervals of a year or more for the carrying on of a series of scientific observations. But with a battery of cameras and spectrographs and the additional instruments with which the average eclipse expedition is equipped a very complete record of an eclipse can be made even within as brief a period as a single minute. With clear skies a single expedition will obtain at least a score of valuable photographs of the corona within two minutes or less, and in addition spectroscopic and other records of the eclipse of great value. If several expeditions at widely separated stations are in the same eclipse path results of correspondingly greater value are to be expected. The records of an eclipse are of value not only in themselves but because they fit into the chain of eclipse records taken at different times in the sunspot cycle and furnish a needed link in the chain of continuous solar changes. For this reason even a single photograph of the corona of an eclipse has a very special value and is greatly to be desired. Every effort should be made for this reason to obtain photographs of the corona at as many

different points as possible in the eclipse path for if clouds occur at one point fair skies may be experienced at another, as was well exemplified in the case of the eclipse of 1923. For this reason plans should be made to obtain observations of the coming eclipse of January 24, 1925, at as many points as possible along the shadow path. Success may be attained where least expected.

An expedition usually arrives at the site selected at least six weeks before the day of the eclipse. This is none too soon for all instruments must be assembled, erected and adjusted. This includes the building of shelters for the instruments, dark rooms, etc., and the erecting of a tower or long horizontal enclosure for the long-focal, telescopic camera, forty, sixty or sixty-five feet in length.

The program of work for each instrument and observer is thought out far in advance and as soon as everything is in readiness rehearsals and drills are held frequently so that during the few vital moments of totality no fatal delay or blunder will occur that might bring to naught weeks of painstaking prparations.

One might imagine that if anyone were to have the opportunity to see the eclipse at its best it would be the astronomer, but in general, he sees less of the eclipse than anyone else. His undivided attention must be given to the instrument or work assigned to him and often he has no opportunity to cast as much as a glance toward the heavens when the corona is shining forth in all of its glory. A noted astronomer who had been on a number of eclipse expeditions once remarked that he had never SEEN a total solar eclipse.

The weeks of his stay at the eclipse camp preceding the day of eclipse are busy and nerve-straining ones for the astron-

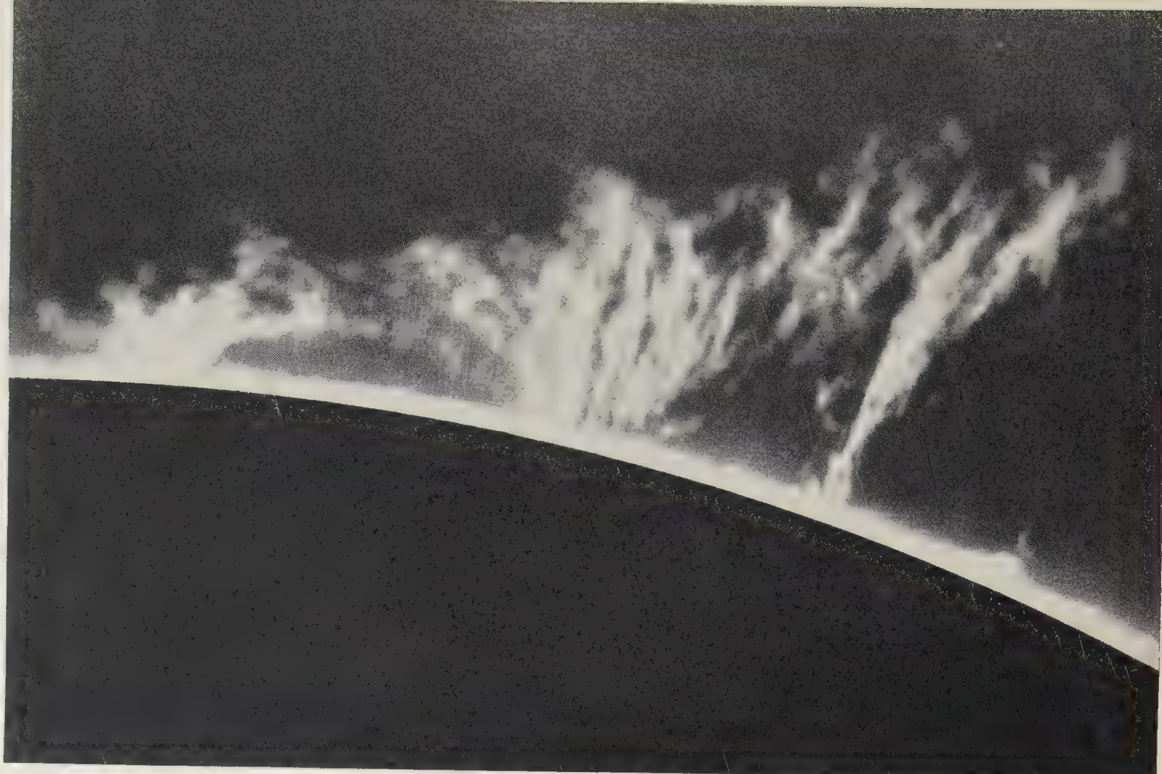
omer. The eclipse cannot be postponed or delayed. Everything must be done by a certain minute on a certain day and there is the ever present anxiety as to what the weather will be during the fateful moments of totality. Will all of his labor be in vain or will it be crowned with success? The god of the weather alone will decide. The astronomer has need to be a good sport or a philosopher, or both.

XX

THE IMPORTANCE OF ECLIPSES

Why spend so much time and money and effort in observing total eclipses of the sun? It might be hard to explain this to the satisfaction of one who measures the value of everything in terms of dollars and cents. Yet even the practical value that may result from the observation of total solar eclipses is by no means negligible. Helium, now used for inflating airships and balloons and far more suitable for this purpose than the inflammable hydrogen gas, was discovered in the flash spectrum of the sun by eclipse expeditions long before it was discovered on earth. Lines of unknown origin, attributed to a hypothetical element, "coronium," have also been found in the corona, and efforts are now being made to "run these lines to earth." There is nothing in this universe more important to us than the sun. We are dependent upon it for our very existence and the laws that govern its output of life-giving heat and energy are of vital interest to us. The corona is intimately associated with and dependent upon the sunspot cycle of solar activity, the cause of which is still a mystery. So far no method has been devised for studying the corona without an eclipse. Find a way to observe the corona in daylight and a great step will be taken toward the solution of the mystery of the sunspot cycle and the variability in the output of solar energy, which is so closely connected with meteorological and magnetic changes on the earth. We need observations of eclipses to tell us more of the secrets of the sun.

In the sun are the same elements with which the scientist



Solar prominences are now photographed continually in broad daylight by means of the spectroscope. The above view shows a prominence 80,000 miles high taken without an eclipse at the Mt. Wilson Observatory, August 24, 1909.

works in his physical and chemical laboratory but in a form and at a temperature that cannot be reproduced here. Eclipse observations of the corona furnish the means for studying the behavior of these same elements and possibly other unknown elements under the unusual conditions that exist at the surface of the sun and in its immediate vicinity. In this great research laboratory of the sun, as in our physical and chemical laboratories on earth, great and far-reaching discoveries may be made.

Of equal importance with the corona as a subject of study during total eclipses of the sun in recent years has been the behavior of rays of light passing through the gravitational field of the sun. Here we may learn something of the nature of light itself. At time of total solar eclipse stars become visible even close to the edge of the eclipsed sun. The light from these stars must pass through the sun's gravitational field before it enters our eyes. Some years ago Prof. Albert Einstein predicted, on the basis of his now celebrated theory of relativity, that light would be deflected from its course upon passing through a gravitational field and that for light passing through the sun's field the deflection would be great enough to be measured. A photograph of the star field surrounding the eclipsed sun was to be compared with the same field of stars photographed some months later when the sun was in another part of the heavens. There should be a displacement of the star images in the field surrounding the eclipsed sun away from the sun and varying in amount with distance of the star image from the edge of the sun. The exact amount of the deflection was computed from the theory and found to be one and seventy-five hundredths of a second of arc for a star at the edge of the sun. This was the maximum deflection and it decreased rapidly with distance outward from the sun,

being too small to measure at a distance of one diameter of the sun.

This "Einstein effect," as it was called, was sought for by the British eclipse expeditions to Brazil and Africa during the total solar eclipse of May 29, 1919, a particularly favorable time as the sun was then in a rich field of stars. Measurements of the photographic plates seemed to show conclusively that such an effect did exist. The Lick-Crocker Expedition to Wallal, Australia, also undertook the solution of the same problem at the time of the total solar eclipse of Sept. 21, 1922. The results obtained were even more favorable to the Einstein theory than those obtained by the British expeditions in 1919, the displacements of a large number of star images, when measured and reduced, giving almost exactly the value predicted from the Einstein theory. The solution of the problem was again undertaken at the eclipse of Sept. 10, 1923, by the Swarthmore College Expedition to Yerbanis, Mexico. The plates obtained by this expedition with their Einstein cameras have not been completely reduced up to the present time.

We are not entering into any discussion of the Einstein theory of relativity here but it must be admitted that there is every reason to believe that light is bent from its course upon passing through the sun's gravitational field as if it were a material substance having mass and weight. This discovery, made solely by the observation of total solar eclipses, is of great importance to the physicist as well as to the astronomer, for it may alter some of his most fundamental conceptions regarding the nature of light. Whether the bending of the rays of light on passing near the sun is due to the Einstein effect or some other cause is the subject of spirited controversy among scientists at the present time. It is best to keep an open mind in this matter so far as possible and await

the accumulation of additional evidence before forming conclusions.

Of secondary importance to these problems, yet by no means to be overlooked, are the observations of the times of the beginning and ending of the total phase of the eclipse, which give a means of comparing the true and predicted positions of the moon in the heavens and correcting and improving the tables upon which the computation of eclipses are based. These observations are also of value in getting at the cause of the irregularities in the motion of the moon, which are of much concern to the theoretical astronomer.

Here also we may mention the value of the calculations of past eclipses in fixing the chronological order of many important dates in history. It is possible for the astronomer, working backward with the aid of tables which give the positions of sun and moon for many centuries, to determine the dates of past solar and lunar eclipses and the location of the tracks of solar eclipses on the earth's surface. Comparing the dates and tracks of these past eclipses with accounts of eclipses mentioned in history, it is possible to determine the chronological order of many important events in history running back as far as several thousand years before Christ. This has often been of great value in settling doubtful or disputed dates in history.

A knowledge of the eclipse Saros and the ability to predict eclipses has at times invested its possessor with almost supernatural powers. Columbus used this knowledge of eclipses to excellent advantage on his third voyage to the New World, possibly saving his own life and that of his companions thereby. This happened in the early spring of 1504, when the Indians on the island of Jamaica were threatening to cut off his food supply. A total eclipse of the moon was

to occur in the evening on the first of March. Calling the chiefs of the tribes together on that day Columbus reproached them with refusing to supply him with provisions and prophesied that the divine vengeance would fall upon them that very night when the moon would change her color and lose her light as a sign of the evils that would be sent upon them from the skies.

As it happened the night of the first of March was clear and the full moon shone brilliantly. At the predicted time, as prophesied by Columbus, the light of the moon began to fail. Sir A. Help, writing of this event in his "Life of Columbus," says,—"At the appointed time the phenomenon took place and the wild howls of the savages proclaimed their abject terror. They came in a body to Columbus and implored his intercession. They promised to let him want for nothing if only he would avert this judgment. As an earnest of their sincerity they collected hastily a quantity of food and offered at his feet. . . He consented to intercede for them, and, retiring to his cabin, performed, as they supposed, some mystic rite which should deliver them from the threatened punishment. Soon the terrible shadow passed away from the face of the moon, and the gratitude of the savages was as deep as their previous terror."

It may be counted not least among the results of sending eclipse expeditions to many corners of the globe that such pitiable exhibitions of fear at the occurrence of these natural phenomena, which were so common in the past even among the more civilized races, are becoming increasingly rare. In their place is appearing an intelligent interest and enthusiasm for increasing the sum of human knowledge through the scientific observation of these most impressive phenomena.

XXI

SOME NOTED ECLIPSES OF THE PAST

IN the historical records of all nations are found many references to eclipses. Such was the superstitious dread and fear with which eclipses were regarded that special note was usually made of their occurrence, the historian sometimes referring to them as signs of divine displeasure or portent of evil.

The earliest eclipse recorded in history is an eclipse of the sun which occurred on October 22, 2136 B. C., in the reign of the Chinese Emperor Chung K'ang. The record tells also of the sad fate of the two court astronomers — Hsi and Ho, — who incurred royal displeasure and were beheaded not only because they failed to predict the eclipse but also because they were so drunk at the time of its occurrence that they could not perform the customary astronomical rites! These consisted at that time, as they do even at the present time in some parts of Asia, of beating drums, sounding gongs and shooting arrows for the purpose of scaring off the black dragon which was on the point of devouring the sun.

The next reference to an eclipse also appears in the Chinese records and was made by Confucius, who stated that an eclipse occurred during the reign of the Emperor Yew Wang, who was known to have reigned from 781 B. C. to 771 B. C. The eclipse referred to has been identified as the eclipse of June 4, 780 B. C.

Records of thirty-six eclipses that occurred between the years 720 B. C. and 495 B. C. appear in the Chun Tsew,

written by Confucius, which is one of the Five Classical Books of China with which every well-educated Chinaman is expected to be familiar. Many other eclipses are recorded in a Chinese historical work of 101 volumes which gives an outline of Chinese history from the earliest times to the end of the Yuen Dynasty, 1368 A. D. Not only eclipses of the sun but also comets are mentioned in this work, but, strange to say, no eclipses of the moon.

There is at least one reference to an eclipse in the Bible. In Amos, VIII, 9, we read:—"And it shall come to pass in that day, saith the Lord God, that I will cause the sun to go down at noon, and I will darken the earth in the clear day." This is plainly a reference to a solar eclipse and the eclipse of June 15, 763 B. C. has been identified as the one meant. This was the eclipse of Ninevah of which there is a contemporary record on an Assyrian tablet. Calculations showed that this eclipse was also total at Samaria, where it was predicted. A passage in Isaiah, XXXVIII, 5-8, is also believed to be a reference to the eclipse of January 11, 689 B. C., visible in Jerusalem.

Six eclipses, namely, three of the sun, including the eclipse of Ninevah in 763 B. C., which were recorded on Assyrian tablets, and three of the moon, observed in Babylon, have fixed the dates of Assyrian chronology with great exactness. The earliest date in Assyrian chronology accurately determined by means of these records of eclipses is the year 911 B. C. Earlier than that date there is much uncertainty as to the exact dates of historical events.

The most famous of classical eclipses and the first to be definitely predicted was that of Thales of 585 B. C., to which we have referred in an earlier chapter, which put an end to the battle between the Lydians and the Medes, and brought

about the conclusion of a lasting treaty. Numerous references to eclipses appear in the writings of Greek historians but it would be impossible to consider any of these in detail here.

Many interesting accounts of eclipses that occurred in the Middle Ages appear in the Anglo-Saxon Chronicle. The first eclipse noted in English chronology was the eclipse of 538 A. D. which occurred in the reign of Henry, King of the West Saxons. The sun's disk was three-fourths covered in London at maximum obscuration.

On October 29, 878 A. D. there was a total eclipse visible in London. No other solar eclipse total in London occurred until the year 1715, more than eight centuries later, though the eclipse of December 22, 968, was very nearly total in London, and also the eclipse of March 20, 1140.

The eclipse of August 30, 1030, is known as "the eclipse of Stiklastad" for the reason that the sun was totally eclipsed on that date in Norway at a place known as Stiklastad while a battle was in progress in which Olaf, the King of Norway, was said to have been killed.

The eclipse of August 2, 1133, total in Scotland, was one of the most noted eclipses of the middle ages. It was taken at that time as a portent of misfortune to Henry the First, who went over sea that year never to return and was on his voyage at the time of the eclipse. His death in Normandy two years later seems to have made a great impression on the popular mind and to have been directly associated with the occurrence of the eclipse. It was alluded to in this connection both in the Anglo-Saxon Chronicle and by William of Malmesbury. The path of this eclipse also crossed Europe, entered Palestine, and passed over Jerusalem.

In 1140 occurred the eclipse that was long supposed to have been total in London but which calculation has shown was

total at Shrewsbury, Derby, Nottingham and Lincoln but not in London. The duration of this eclipse in England was nearly three and a half minutes. One of the most celebrated eclipses of the middle ages was the eclipse of June 17, 1433, which was total in Scotland, the hour of the eclipse being long remembered there as the "Black Hour", as totality was exceptionally dark. The duration of totality at Inverness was over four and a half minutes, and at Edinburgh about three minutes and forty seconds. The path of this eclipse also passed over Bavaria and Asia Minor to Arabia and was observed in Turkey near sunset. Scotland was again favored with a total eclipse on "Black Saturday," February 25, 1598, and on "Mirk Monday," April 8, 1652. In all three of these eclipses Edinburgh lay directly in the path of totality. Again in 1699 the sun was eleven-twelfths obscured at Edinburgh so this town appears to have been particularly favored by eclipses during the middle ages. In London, on the other hand, no total solar eclipse was visible for over eight centuries.

On May 3, 1715, however, London came at last within the path of a total solar eclipse. This eclipse track crossed England from Cornwall to Norfolk and was observed by one of the most noted astronomers of the time, Sir Edmund Halley. No other total eclipse has passed over London since that day and there is none in prospect for more than a hundred years to come, though in 1724 another path of totality crossed the southern part of England at no great distance from London. The next total eclipse visible in England is that of June 29, 1927, of which we will have more to say in the next chapter.

Mention has been made of eclipses observed in the British colonies and, later, in the eastern part of the United States in the latter part of the eighteenth century and during the

nineteenth century. We are now coming to a period of scientific enthusiasm for the observation of eclipses, and the inauguration of the long series of eclipse expeditions that have obtained such brilliant results both in this country and abroad.

In the early ages men were, in general, too inspired with feelings of awe and fear during the period of totality to make any observations of value. The corona was referred to occasionally as a luminous ring of light but its true nature as a solar appendage of unusual significance was not recognized until near the middle of the last century. Some believed even then that both corona and "red flames," as the prominences were called, were appendages of the moon instead of the sun.

Even scientific observers of eclipses hardly knew what to look for at time of eclipse until the nineteenth century was well advanced. The present scientific enthusiasm for observing eclipses, which has resulted in the dispatch of expeditions to the shadow path of practically every eclipse available within the past sixty years or more, dates back to the discovery of Baily's Beads at the annular eclipse of May 15, 1836. Though but a minor and unimportant phenomenon it was the first really scientific contribution to the brilliant series of eclipse observations and discoveries of modern times. This discovery, made by Sir Francis Baily, who was not an astronomer by profession, shows what may be accomplished even by the amateur observer in the field of astronomy as well as other sciences.

The eclipse of July 8, 1842, crossed Europe from France to Russia and some of the most noted astronomers of the day were stationed at different points along the central line to observe it. Fortunately the eclipse was witnessed under

favorable circumstances at all points. Attempts were then made for the first time to photograph the corona on iodized paper but without any results.

The various features of this eclipse were particularly beautiful and made a deep impression upon the masses of people who observed it, as well as upon the astronomers. Baily again observed the "Beads" at Pavia, as well as the magnificence of the corona and the prominences. He refers to the latter as "three large protuberances apparently emanating from the circumference of the moon but evidently forming a portion of the corona." In speaking of the corona he says, "The breadth of the corona, measured from the circumference of the moon, appeared to me to be nearly equal to half the moon's diameter. It had the appearance of brilliant rays. Its color was quite white, not pearl color, nor yellow, nor red." Of its first appearance at the beginning of totality he says, "I was astounded by a tremendous burst of applause from the streets below, and at the same moment was electrified at the sight of one of the most brilliant and splendid phenomena that can be imagined. For at that instant the dark body of the moon was suddenly surrounded with a corona or kind of bright glory."

The enthusiasm aroused by the observations of this eclipse had much to do with the fitting out of expeditions to observe the eclipse of July 28, 1851, visible in Norway and Sweden and northern Europe. Many prominent astronomers were again on hand, including G. P. Bond of Harvard, probably the first American to visit Europe for the express purpose of observing a total solar eclipse. Again the skies were clear. The first photograph of an eclipse was made on this occasion, a daguerreotype by Busch at Königsberg. At this eclipse also the Astronomer-Royal of England, Sir George Airy, and other

observers saw the enormous lunar shadow speeding away through the air for a period of fully six seconds after totality was over.

It is impossible to even touch upon the long series of eclipse observations that have been made from that time up to the present day. The systematic application of photography to the study of the corona was inaugurated at the time of the eclipse of July 18, 1860, the first one observable in the United States after the scientific observation of eclipses had begun.

The first fruits of the application of photography to the study of eclipse phenomena resulted in the discovery at this eclipse that the "protuberances" or prominences belonged to the sun and not to the moon. This became plainly evident from a study of the photographs.

It was about this time that the spectroscope was coming into use as an instrument of research in the study of the constitution of the stars and sun and it was first employed in unravelling the mystery of the composition of the corona and prominences at the eclipse of August 18, 1868, which was visible only in India, Siam and the Malay Peninsula. Undaunted by the discouraging fact that this eclipse was to occur so far from home, British, French, German and Spanish expeditions set out for this far-away track and the brilliant success attained was well worth the effort. The prominence lines were of remarkable brilliancy. Hydrogen was easily identified and the bright yellow line of the, then unknown, element helium was strongly in evidence. The success of Janssen in observing the prominences with the spectroscope after the eclipse was over has been mentioned elsewhere.

From now on the astronomer used effectively these two powerful aids, the camera and the spectroscope, on all eclipse expeditions. Little could be accomplished without them. It

is now but a matter of time before the mysteries of the corona will be solved by means of them. The chief obstacle in the way of rapid advance in the solution of the cause of the intricate form and structure of the corona and its association with the sunspot cycle lies in the extreme briefness of the time allowed for making observations at each eclipse,—on the average scarcely three minutes.

Yet in the past half century, in which a total period of considerably less than one hour has been available for the study of the corona and the field immediately surrounding the sun, many valuable photographic and spectroscopic records of eclipses have been accumulated. From the middle of the nineteenth century up to the present time the work of obtaining scientific records of eclipses has been carried on at every total solar eclipse that has been visible in whatever part of the world it may have occurred, outside of polar regions.

It has become, indeed, almost a matter of tradition among astronomers of today to "carry on" in the matter of sending out expeditions for the observation of total eclipses of the sun and future generations of astronomers will find little to criticize in the splendid series of eclipse observations contributed by the astronomers of the present generation. The scientific enthusiasm of the astronomers of the present age is reflected in the quality, as well as the quantity, of valuable records of solar eclipses that are being collected by eclipse expeditions.

XXII

SOME TOTAL SOLAR ECLIPSES OF THE NEAR FUTURE

After the total solar eclipse of Jan. 24, 1925, has passed into history the American astronomer will have to do most of his eclipse observing abroad. There will be a fine total-annular eclipse visible in the northwestern states on April 28, 1930, but aside from that no total solar eclipse track will pass over any considerable portion of the United States until Feb. 26, 1979, when the path of totality will pass over the northwestern States again to Canada and Hudson Bay. The eclipse of March 7, 1970, will be visible in the United States but only in the state of Florida. There are, however, some fine eclipses due to arrive in the immediate future in other lands and these should be well observed.

On June 14, 1926, there will be a total solar eclipse of over four minutes' duration that will pass from East Africa over the Indian Ocean to Sumatra, Borneo and the Philippines. It is probable that every effort will be made to observe this eclipse as it will occur under very favorable circumstances. The most suitable stations will probably be found in Sumatra. It was on this island that the U. S. Naval Observatory expedition occupied three stations, Solok, Sawah Loento and Fort De Kock at the time of the total solar eclipse of May 17, 1901, and obtained some excellent photographs of the corona and "flash spectrum."

The 1926 eclipse will occur in Sumatra about two o'clock in the afternoon and in the Philippines shortly before sunset. The maximum duration of 4 min. 10 sec. will occur in mid-ocean south of India. On the east coast of Africa, where the eclipse will take place in the early morning, the duration will be a little over two minutes but in Sumatra it will last over three minutes, which is about the average duration of a total solar eclipse.

The eclipse of July 9-10, 1926, is an example of an eclipse track that is completely wasted from the astronomer's point of view. It is, to be sure, an annular eclipse and so its scientific value is small compared with that of a total eclipse but its track from beginning to end lies wholly over the Pacific Ocean, touching only a few small unnamed islands to the northwest of the Hawaiian group.

The most interesting eclipse of the near future, after the eclipse of 1925, will be the total solar eclipse of June 29, 1927. The path of this eclipse touches the earth at sunrise at a point in the Atlantic Ocean to the southwest of the British Isles, in approximate position 41° N. Lat. 16° W. Long. Just missing the southern coast of Ireland it crosses St. George's Channel to Liverpool and then passes diagonally over northern England to the coast at Seaham Harbor in Durham. From here it passes over the North Sea to Norway, touching the coast in approximately 58° N. Lat. and 10° East Long. Passing about midway between Trondhjem and Christiania in Norway it crosses the northern part of Sweden to the Arctic Ocean. Leaving the Norwegian coast in about 70½° N. Lat. and 29½° East Long. it then runs over the Arctic Ocean north of Nova Zembla to Thaddeus Bay, Siberia, and from here across the northeastern part of Siberia, north of Kamchatka

to the Bering Sea, where it leaves the earth at sunset at a point just north of the Aleutian Islands.

This eclipse will be one of the briefest total solar eclipses on record. The longest duration, which will occur at a point on the central line north of Nova Zembla near noon, will be only fifty seconds. The duration in England will be, at the most, about twenty-five seconds. On the Scandinavian peninsula the duration on the central line will range from thirty seconds to forty-five seconds.

The total phase of the eclipse will occur at Liverpool at 5:23 A. M. and its duration at this place will be only seventeen seconds. At Durham the total eclipse will take place at 5:25 A. M. and its duration will be only nine and six-tenths seconds. In this eclipse the apex of the moon's shadow cone will barely graze the earth's surface and the path will be extremely narrow.

Though the total phase of the eclipse occurs in England about half past five in the morning the sun rises at about half past three in northern England at this time of the year so the entire eclipse will take place with the sun above the horizon. The partial phase will be large all over England, Scotland and Ireland, as well as in the northern and northwestern part of Europe, the northeastern part of Siberia and Alaska. The magnitude of the eclipse will be 96% in London, 98% in Edinburgh and Dublin and 97% in Glasgow, Oxford and Cambridge. At Nome, Alaska, and magnitude of the partial eclipse will be 86%.

It might be imagined that no scientific results of great value could be obtained at total eclipse when the duration is so extremely short, but this is not necessarily true. The spectroscopic observations of the "flash", and chromosphere, the

lower solar atmosphere, should be of particular value as they will be seen to better advantage than at the time of a large total eclipse when the lower atmosphere, as well as the disk, of the sun is covered by the moon. At this eclipse the chromosphere should be seen during totality as a rosy circle of light surrounding the sun. The scenic features of the eclipse should be particularly beautiful for this reason and also because the sunspot maximum period will be approaching when the solar activity is above normal and manifests itself in numerous prominences and a brilliant corona.

Though it will not be possible to take photographic exposures of any great length a large number of short exposures could be taken at different points if weather conditions were favorable, especially if expeditions were scattered along the path in England, Norway, Sweden and northeastern Siberia. At this time of year the chances are that clear skies would favor the observers at many points. The possibilities of obtaining valuable results at this eclipse are by no means to be overlooked. The eclipse will be anticipated with unusual interest in England, moreover, as it will be the first total solar eclipse visible in England in over two hundred years and the last that will be total in this country until Aug. 11, 1999, when the path of totality may graze the south of Ireland and Land's End.

Another interesting total solar eclipse of the near future will be the splendid eclipse of May 9, 1929, of over five minutes' duration, occurring shortly after noon in Sumatra and visible also in the Malay Peninsula and the Philippines. The eclipse of October 21, 1930, with a duration of less than two minutes will pass over Melanesia, Polynesia and the southern Pacific to Patagonia, where it will end at sunset. The eclipse of April 28, 1930, which is a total-annular eclipse, that

is, annular in one part of its course and total in another part, will pass from the Pacific Ocean over the northwestern and north central part of the United States to Canada, Hudson Bay and Labrador. The eclipse will occur at noon in the United States, in Oregon or Idaho, and it will probably be total in this part of its path for a brief period. After the eclipse of Jan., 1925, this will be the most interesting eclipse of the twentieth century visible in the United States. The eclipse of August 31, 1932, duration one and a half minutes, will come down from Baffin Land across Hudson Bay to Labrador and will end at sunset in mid-Atlantic. This eclipse will be visible as a large partial eclipse in the north-eastern part of the United States.

Three eclipses of the present century will first touch land in the United States at sunrise but will almost immediately pass out of the country. The eclipse of July 9, 1945, will begin in the extreme northern part of the United States, either in Idaho or Montana, and then will pass across the central part of Canada to Hudson Bay and over Norway and Sweden and Russia to Turkestan. This will be a fine eclipse in Canada and Europe but of little value in the United States as the sun will be in, or very close to, the horizon. The same may be said of the eclipse of June 30, 1954, which closely parallels the course of the 1945 eclipse, beginning at sunrise in North Dakota and passing over Canada, Scandinavia, Russia and Asia to India. On October 2, 1959, the sun will rise eclipsed on the New England coast but the path will then pass over the Atlantic to Africa and across this continent to the Indian Ocean.

The eclipse of 1927 is the last one for which computations have been completed in the Nautical Almanac Office up to the present time (1923). The circumstances of the later eclipses

have been taken from Oppolzer's Canon der Finsternisse. The eclipse tracks shown on the charts in which book were plotted from only three calculated points and they are in some cases off from the true positions as much as a hundred miles. They show closely enough for ordinary purposes, however, the approximate positions of all total and annular eclipses for more than two centuries to come.

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